APPENDIX H

Hydrologic Analysis of Upper Columbia Alternative Operations, including VARQ Flood Control Plan, at Hungry Horse Dam, Montana

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Errata Sheet—
Upper Columbia Alternative Flood Control (VARQ) and Fish Operations EIS –
   Hydrologic Analysis of Upper Columbia Alternative Operations, including the
   VARQ Flood Control Plan at Hungry Horse Dam, Montana

Nomenclature Corrections

The following should be used when reading the subject report. Alternatives are the convention for the sections of the EIS addressing the Pend Oreille River Basin.

Standard FC: corresponds to **Alternative HS** in the EIS

VARQ FC: corresponds to **Alternative HV** in the EIS

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1.0 Overview

The VARQ flood control plan was first developed by the US Army Corps of Engineers (Corps) in the late 1980s. The current VARQ flood control plan has had some changes and refinements from the original plan but the basic logic is still the same: More water is held in storage at Hungry Horse Reservoir during the winter months in those years when local downstream flooding is not anticipated. This results in higher reservoir elevations and discharges during the spring refill period with associated benefits to resident and anadromous fish. The VARQ flood control plan was identified in both the US Fish and Wildlife Service's (USFW Biological Opinion) and National Marine Fisheries Service's (NMFS Biological Opinion) December 2000 Biological Opinions[1,2] as an action that should be taken for the benefit of bull trout in Hungry Horse Reservoir and anadromous fish downstream in the Columbia River.

2.0 Hydrologic Analysis

The hydrologic analysis compares the VARQ and standard flood control procedures (Standard FC) for Hungry Horse Reservoir, and describes the associated hydrologic effects downstream. Impacts to reservoir elevations, reservoir discharges, spill, and local flood control from Hungry Horse Reservoir downstream to Albeni Falls Dam were analyzed. Figure 1 shows a vicinity map of the affected area. This analysis simulates Hungry Horse operations under the two different flood control procedures using the hydrology during the period 1929-2002. RiverWare™, a general river basin modeling software tool, developed by CADSWES University of Colorado, Boulder, Colorado, was used to model the two different flood control procedures. The model operates at a daily timestep using limited foresight as to reflect the uncertainty associated with "real-time" operations. The model operates in a continuous mode, utilizing reservoir carry-over effects from the previous year rather than reinitializing every year. This method was used for every reservoir represented in the model (Hungry Horse, Flathead Lake, Pend Oreille Lake).

2.1 Period of Record

A 74 year record (1929-2002) was used in this study. Many significant floods (1954, 1964, 1974, and 1975) and drought years (1941, 1977, and 2001) have occurred during this period. This wide range of water supply conditions works well when comparing the two different flood control procedures and how they affect local flood control, spill potential, and refill.

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[1] US Fish and Wildlife Service – Regions 1 and 6, "Biological Opinion – Effects to Listed Species from Operations of the Federal Columbia River Power System", December 20, 2000, p.84.

[2] National Marine Fisheries Service – Northwest Region, "Endangered Species Act – Section 7 Consultation, Biological Opinion - Reinitiation of Consultation on Operation of the Federal Columbia River Power System Including the Juvenile Fish Transportation Program, and 19 Bureau of Reclamation Projects in the Columbia Basin" December 21, 2000, pp. 9-63,9-64.
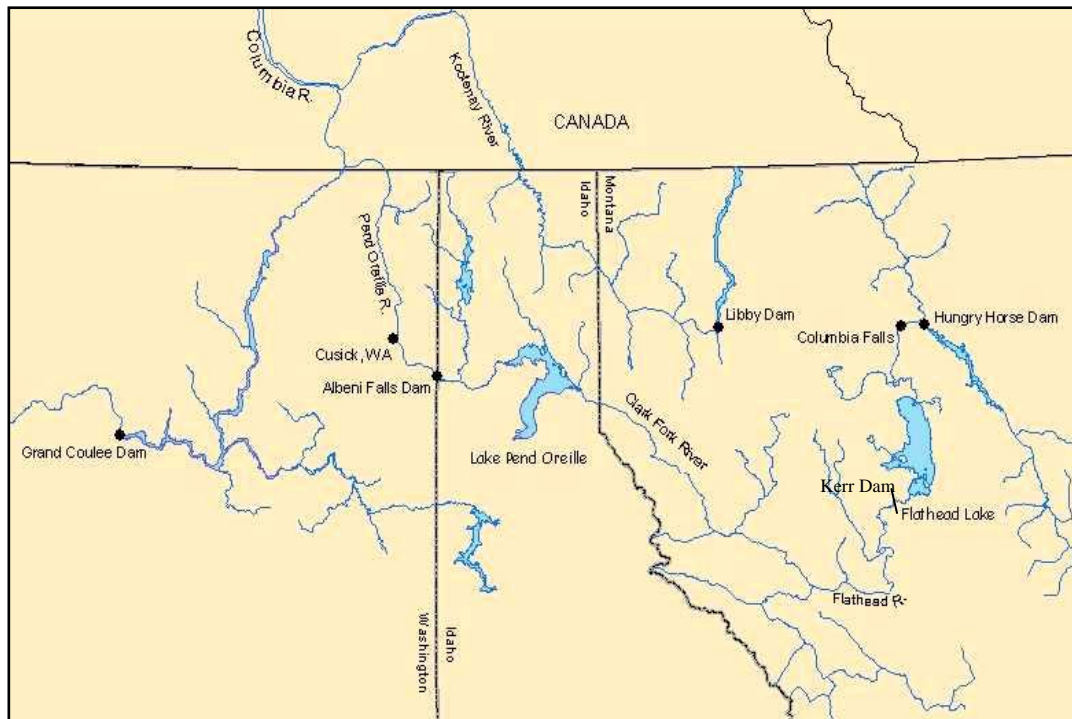
Figure 1: Vicinity Map including Hungry Horse, Kerr, Albeni Falls, and Grand Coulee Dams.

2.2 Simulated Water Supply Forecasts

Hydrologic studies and modeling efforts often require a complete set of historic forecasts in order to more accurately analyze a proposed change in operating procedures. The results of using inflow forecasts, rather than observed historic runoff, adds uncertainty about future conditions and more closely mimics real-time operations. Therefore water supply forecasts along with actual observed runoff were used in the model simulations. The U.S. Bureau of Reclamation (Reclamation) has developed a data set of monthly forecasts (January through June) for May-September inflow volume for the 1929 to 2002 period[3]. This dataset utilizes the current Reclamation forecast equation for the period 1944-2002, a modified Reclamation equation for 1932-1943, and borrows Kuehl-Moffitt forecasts for 1929-1931.

2.3 Modeling Methodology

Modeled Hungry Horse operations were dictated by a set of guidelines which set the appropriate release from the dam. These guidelines included flood control, variable draft limits for power (VDL curves), minimum flows at Hungry Horse and Columbia Falls, refill procedures, local flood control, flow augmentation, and ramping rates.

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[3] "DEVELOPMENT OF MONTHLY INFLOW FORECASTS FOR HUNGRY HORSE RESERVOIR FOR THE PERIOD 1929-2002", Draft, prepared by Ted Day of the Bureau of Reclamation, PN Region, Boise, ID, March 2003

2.3.1 Flood Control Drafts

Flood control elevations were calculated using the monthly inflow (May-September) forecasts and the respective storage reservation diagrams (Figures 2 and 3). Flood control storage reservation diagrams are graphs used to determine the amount of flood control space necessary to capture anticipated spring runoff.
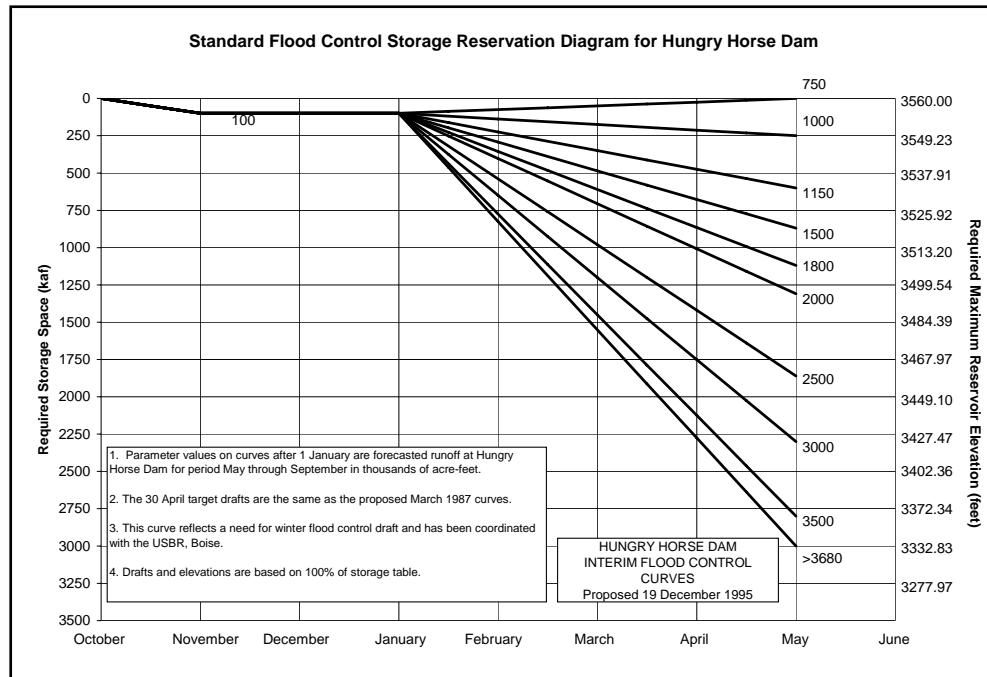
Figure 2: The Standard Flood Control Storage Reservation Diagram for Hungry Horse Dam
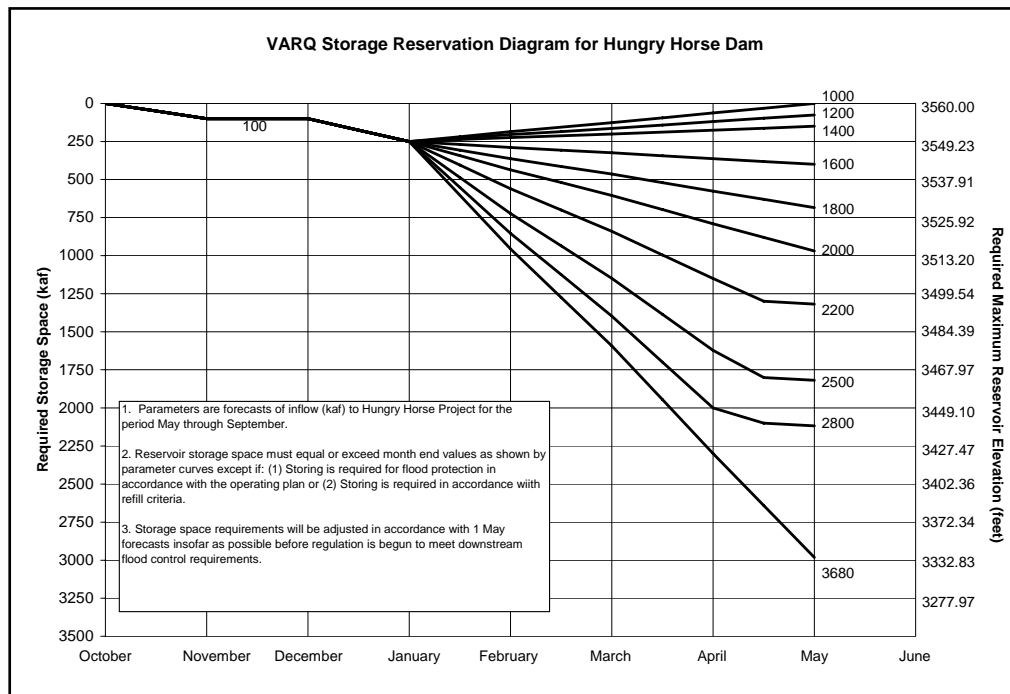
Figure 3: The VARQ Storage Reservation Diagram for Hungry Horse Dam

On January 1 of every year, the flood control space requirement is slightly greater with VARQ at 250,000 acre-ft as compared to 100,000 acre-ft for Standard FC. In 1997 Reclamation requested the Corps to increase the winter space requirement at Hungry Horse from 100,000 acre-ft to 250,000 acre-ft as an addition to the VARQ rule curves. The 250,000 acre-ft space requirement would not only provide more protection against winter rain events but it would also provide a smoother transition from minimum flows to winter flood control releases in wetter years. During most years, Hungry Horse is already drafted below the 250,000 acre-ft requirement by January 1. The 20 foot draft for anadromous fish in the summer along with the minimum flow requirement at Columbia falls usually result in Hungry Horse Reservoir having more space than 250,000 acre-ft on January 1. During the winter drawdown period (January through April), in years when flooding is not anticipated, the VARQ flood control plan allows Hungry Horse Reservoir to be more full than Standard FC. In years with high runoff conditions, VARQ will require drafting Hungry Horse to the same elevation by the end of April as was required by Standard FC. Because the reservoir is generally fuller during the winter with VARQ flood control, there is less space to fill which results in higher reservoir releases during the spring refill period and better assurance of refill. The calculated flood control elevations acted as an upper limit in which to operate the reservoir.

In order to accurately simulate real time operations, flood control releases were limited to maximum turbine discharge (around 12,000 cfs) plus 2000 cfs during the month of April. The assumption was that spill of less than 15% of the total discharge (around 2000 cfs at full power plant capacity) would not violate the Montana state water quality standard of 110% for total dissolved gases. As a result the May 1 reservoir elevations are above the flood control rule curves in some years.

2.3.2 Power Drafts

Variable draft limit (VDL) elevations were also calculated using the forecasts and flood control elevations. The VDL curves act as a lower operating limit; these curves allow reservoir drafts for power while still maintaining a 75% probability of reaching April 10 flood control elevations. These power drafts in the winter actually alleviated some of the large April flood control drafts in high volume runoff years by pre-drafting the reservoir. VDL curves are in effect from January 1 until April 10. After April 10, VDL curves are the same as the flood control rule curves.

2.3.3 Minimum Releases

Minimum releases set at Hungry Horse were determined by either the flow requirement below Hungry Horse or the flow requirement at Columbia Falls depending on whichever one was greater. The minimum flows were calculated using the Hungry Horse inflow forecast and guidelines as set forth in the USFW Biological Opinion. The minimum flows at Hungry Horse and Columbia Falls are updated every month between January and March, after the final inflow volume forecast for the month is issued. The March final forecast sets the minimum flows for the rest of the calendar year. Table 1 shows how these minimum flows are calculated.

Table 1: Minimum Flows at Hungry Horse and Columbia Falls

April – August inflow forecast (kaf)	Hungry Horse min flow (cfs)	Columbia Falls min flow (cfs)
< 1190	400	3200
1790 > forecast > 1190	Interpolate between 400 and 900	Interpolate between 3200 and 3500
> 1790	900	3500

2.3.4 Refill

Refill at Hungry Horse was initiated approximately ten days prior to when streamflow forecasts of unregulated flow were projected to exceed the Initial Control Flow (ICF) at The Dalles, Oregon. For Standard FC, Hungry Horse discharges (May-June) were calculated using forecasted inflow volumes, targeting refill by the end of June, and using a constant release. For VARQ flood control, Hungry Horse discharges (May-June) were calculated using the VARQ operating procedure[4]. This procedure follows a series of rules to set the VARQ outflow at Hungry Horse. These Rules, with the exception of Rule 6, were followed in every year of the VARQ simulation. Rule 6. Inflows Less Than VARQ Outflows states "At the initiation of refill, if inflows are less than the VARQ outflow, pass inflow until inflows rise to the VARQ level. Thereafter, if inflows drop below the VARQ outflow, pass inflow until they rise again to the VARQ level." For the VARQ simulations it was decided to continue to draft Hungry Horse Reservoir by using the calculated VARQ outflow and not hold the reservoir steady by passing inflow. Filling transition curves were used to adjust and set Hungry Horse discharges for final refill. Identical filling transition curves were used for both Standard FC and VARQ. The filling transition curves used reservoir elevations and forecasted (4 days) average daily inflow to set the outflow.

2.3.5 Local Flood Control

Discharges at Hungry Horse were limited to maintain the stage at Columbia Falls below 13 feet (~44,500 cfs). Flood stage at Columbia Falls is at 14 feet (~51,500 cfs), but there is some minor localized flooding above 13 feet. Hungry Horse releases were decreased to 300 cfs when required for local flood control. The absolute minimum flow for Hungry Horse is 145 cfs. However, to maintain power system reliability, Reclamation attempts to keep two units running at speed no-load (~300 cfs). When the elevation at Hungry Horse Reservoir reached 3555 feet, the local flood control requirement at Hungry Horse (i.e. discharges at 300 cfs) was relaxed in order to prevent the reservoir from filling too early. However, Hungry Horse Reservoir was allowed to fill to 3561 feet (1 foot of surcharge) whenever practical to limit flooding at Columbia Falls. Hungry Horse filled above elevation 3560 feet 3 out of 74 years for the VARQ simulation and 2 out of 74 years for the Standard FC simulation.

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[4] U.S. Army Corps of Engineers, Northwestern Division, North Pacific Region, Portland, Oregon, "VARQ Operating Procedures for Hungry Horse Dam", February 2001. Appendix A

2.3.6 Flow Augmentation

Modeled flow augmentation from Hungry Horse Reservoir was in accordance with the NMFS Biological Opinion Action 19, which states: " The Action Agencies shall limit the reservoir draft to elevation 3,540 feet by August 31 for salmon flow augmentation". Reservoir elevation 3,540 feet was targeted on August 31 of every year in the simulation model runs.

2.3.7 Ramping Rates

Changes in Hungry Horse discharges were limited by ramping rates as set forth in the USFW Biological Opinion. These ramping rates are based on flows in the Flathead River at Columbia Falls. Table 2 shows the ramp-up and ramp-down rates for Hungry Horse discharges.

Table 2: Daily ramp-up and ramp-down rates for Hungry Horse Dam

Flow Range (cfs, measured at Columbia Falls)	Ramp Up Rate, Daily Max (cfs)	Ramp Down Rate, Daily Max (cfs)
3,500 - 6000	1,800	600
> 6,000 - 8,000	1,800	1,000
> 8,000 - 10,000	3,600	2,000
> 10,000 - 12,000	No Limit	2,000
> 12,000	No Limit	5,000

2.4 Modeled Results

The output from the Standard FC and VARQ model simulations was analyzed to determine any effects on flows and reservoir elevations from Hungry Horse Reservoir downstream to the Pend Oreille River below Albeni Falls Dam.

2.4.1 Effects at Hungry Horse Dam

The VARQ and Standard FC model simulations reflect operations that are driven by spring flood control operations, year-round minimum flow targets, summer flow augmentation releases, and winter flood control and power drafts. Hungry Horse pool elevations and discharges are frequently different between the two flood control procedures, especially in the winter and spring when flood control drafts have the greatest influence on operations. In most years of the simulations and particularly in years with an inflow forecast (May-Sep) of less than 2.4 million acre-feet (maf), reservoir elevations were higher on May 1 under VARQ Flood Control then with Standard FC. This is in large part due to the deeper flood control draft requirements of Standard FC for these years. For years with an inflow forecast (May-Sep) greater than 2.4 maf, flood control requirements for May 1 are similar for both Standard FC and VARQ. Figure 4 compares the May 1 reservoir elevation for Standard FC and VARQ as related to the seasonal volume forecast.
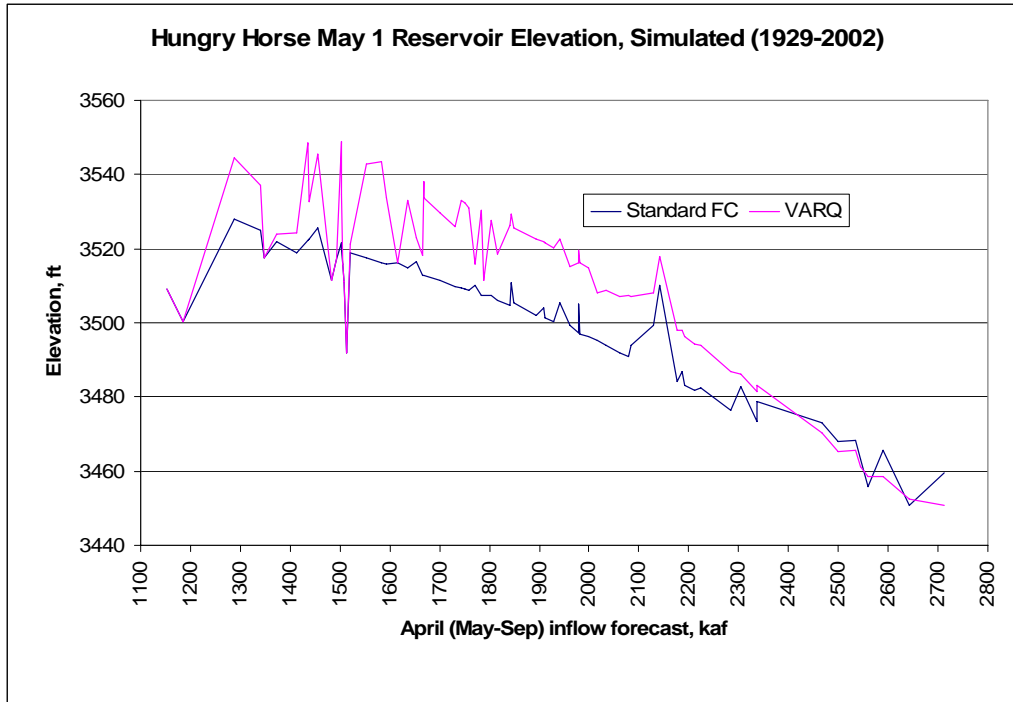
Figure 4: Simulated May 1 Hungry Horse Reservoir Elevations.

The higher May 1 reservoir elevations resulted in slightly better refill probabilities for VARQ. Figure 5 shows the percentage of years that Hungry Horse refilled to within a specified distance from full for both Standard FC and VARQ. The reservoir refilled to within 1 foot from full in 64.9% of all years for VARQ and 62.2% of all years for Standard FC.
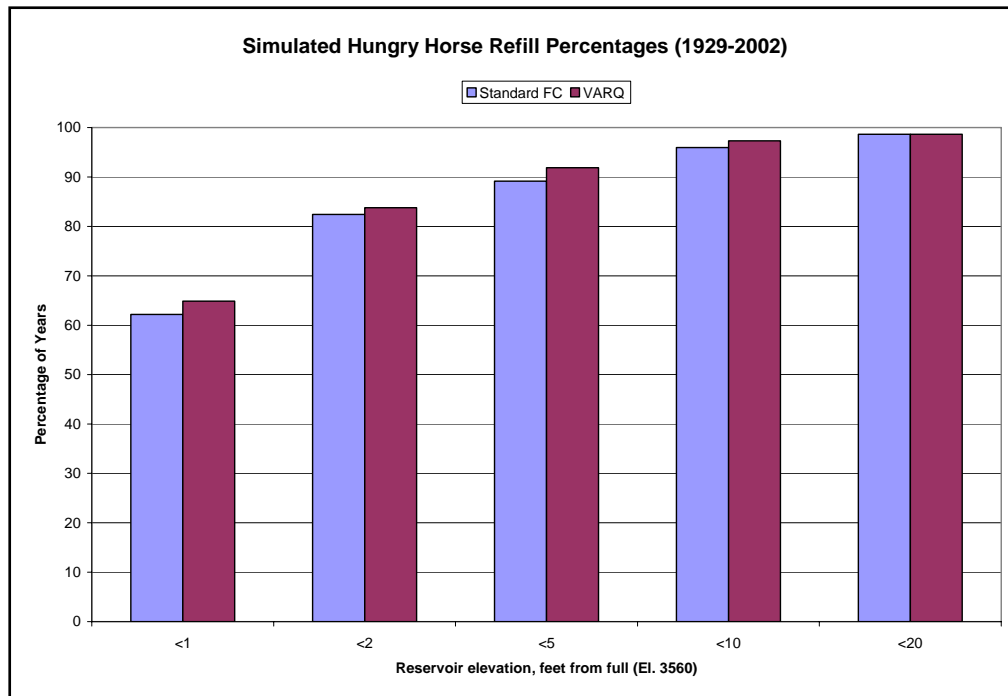
Figure 5: Simulated Hungry Horse Reservoir Refill Percentages.

Figure 6 compares the peak daily elevation reached during the summer refill period (June/July) for both Standard FC and VARQ. Figure 6 reaffirms the slightly higher probability of refill for VARQ.
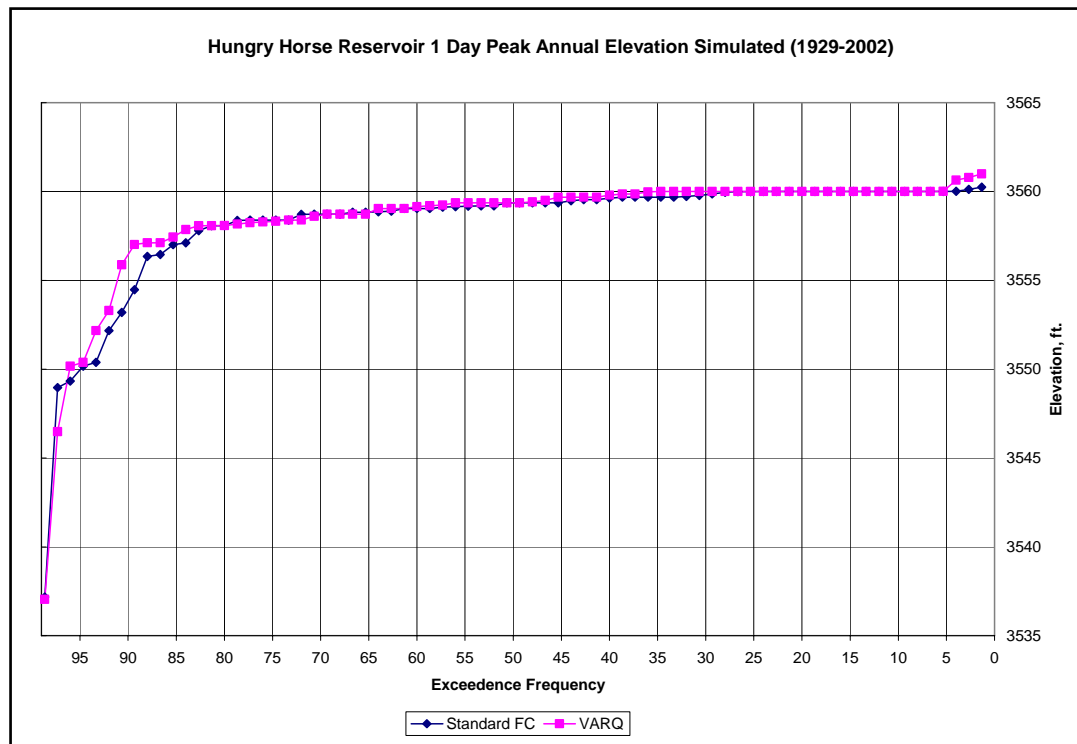
Figure 6: Frequency Curves for Hungry Horse Reservoir, 1 Day Maximum Elevation.

The generally higher May 1 elevations for VARQ also resulted in higher discharges from Hungry Horse in May and June than with Standard FC. Conversely, the deeper drafts that are required for Standard FC in April result in higher discharges for that month than under Standard FC. Larger space requirements, during the winter (January, February), also resulted in higher discharges for Standard FC during those months. Figure 7 compares average monthly discharges for Standard FC and VARQ.
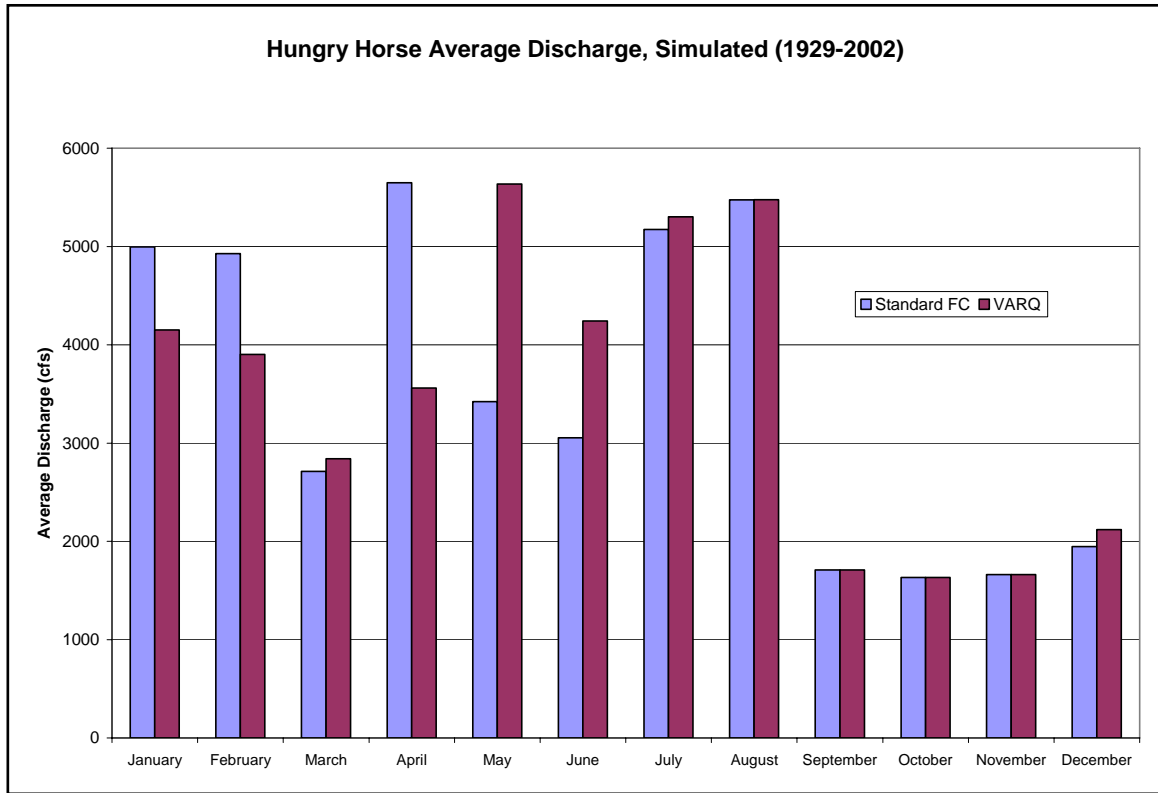
Figure 7: Average Monthly Hungry Horse Dam Discharges.

Figure 7 shows that average discharges are slightly higher for VARQ in December. Increased discharges occurred in years with high fall inflows when Hungry Horse was making releases in December for flood control. Hungry Horse releases in these years were higher under VARQ than Standard FC because of the larger end-of-December space requirement for VARQ (250 kaf vs.100 kaf). In most years, discharges during December reflect the minimum flow requirement for Columbia Falls, which is identical for both VARQ and Standard FC. Table 3 shows the years with increased December discharges for VARQ and the volume difference between VARQ and Standard FC.

Table 3: Years with Increased Hungry Horse Discharges in December for VARQ.

Years	Hungry Horse Discharge Volume Difference between VARQ and Standard FC, December (acre-feet)
1933	145,000
1959	145,000
1968	81,000
1985	122,000
1989	145,000
1995	145,000

In some cases, a change in the volume forecast combined with significant snowmelt runoff required discharges to be at power plant capacity or higher for most of April. Flood control releases were limited to maximum turbine discharge (around 12,000 cfs)

plus 2000 cfs whenever possible. Figure 8 shows the duration curves for Hungry Horse discharges for April. April discharges are much higher under Standard FC. The higher discharges of VARQ are evident in the flow duration curves for May and June as shown in Figures 9 and 10.

Hungry Horse Discharge Duration Analysis (April), Simulated (1929-2002)
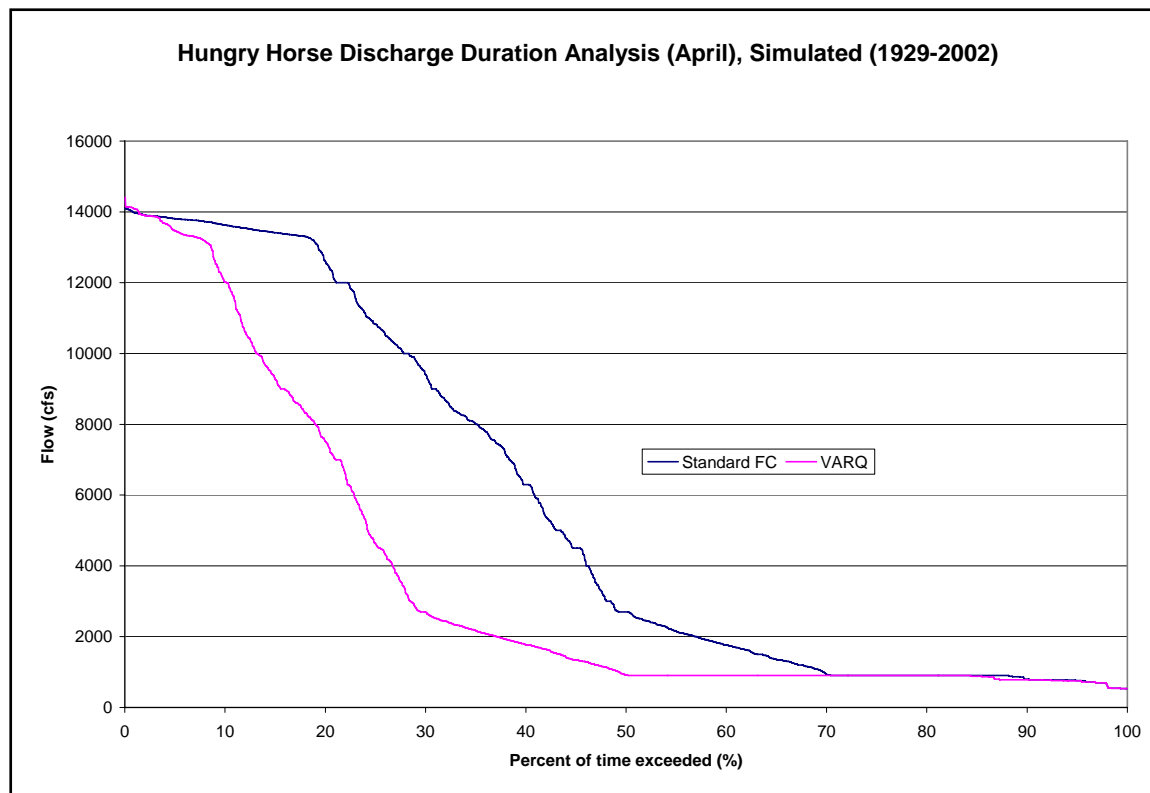

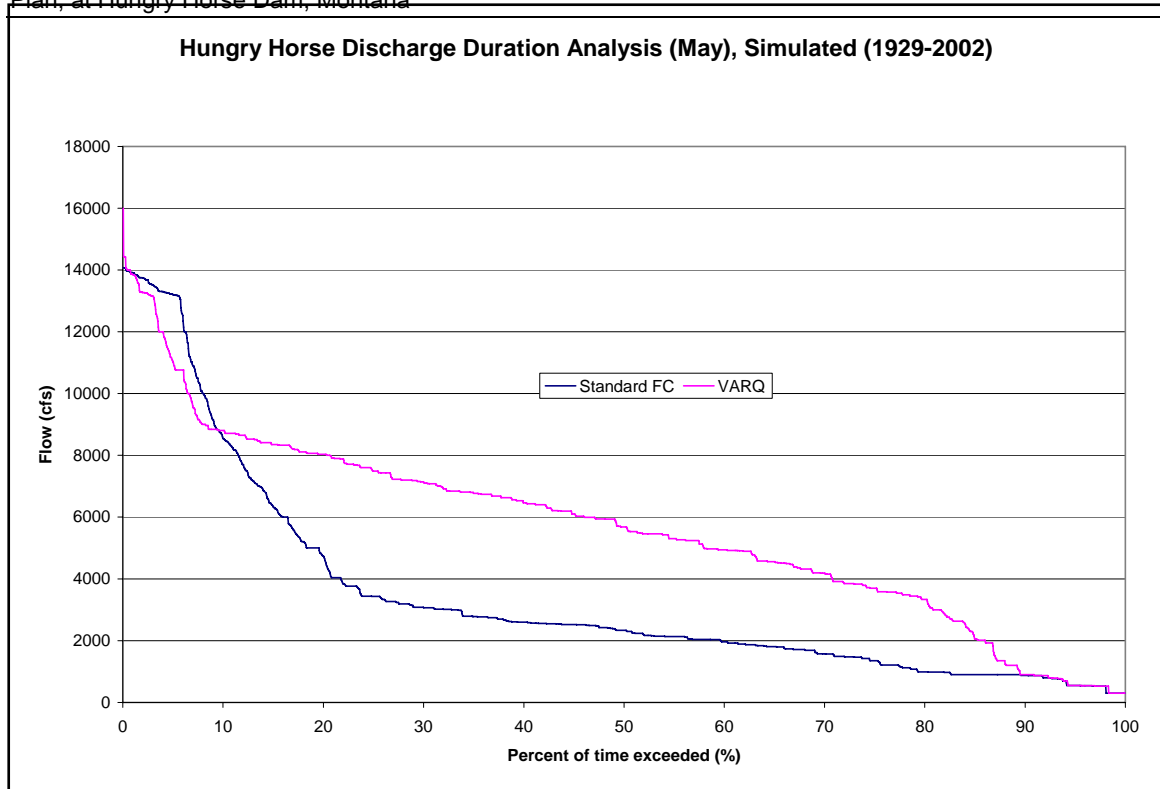**Figure 8: Simulated Hungry Horse Discharge Duration Curves for April.**

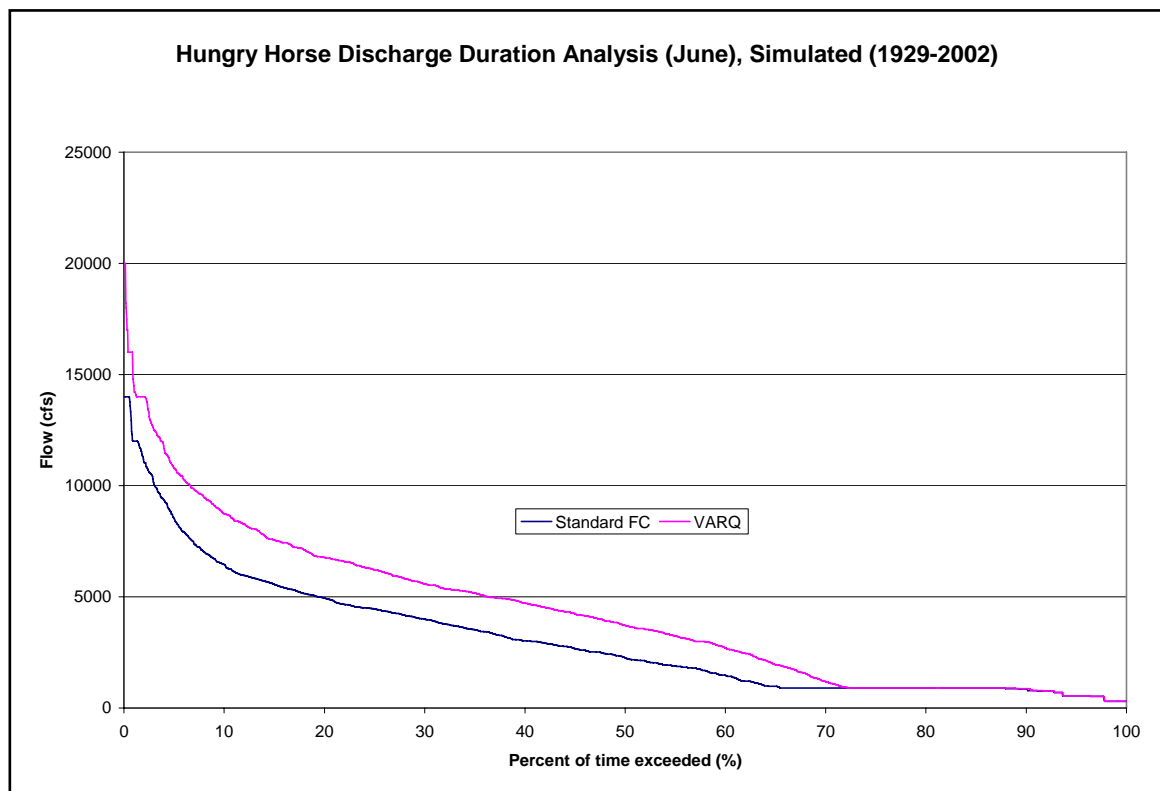**Figure 9: Simulated Hungry Horse Discharge Duration Curves for May.**

Figure 10: Simulated Hungry Horse Discharge Duration Curves for June.

Simulated Hungry Horse discharges in April were guided by the assumption that spill of
less than 15% of the total discharge (around 2000 cfs at full power plant capacity) would
not violate the Montana state water quality standard of 110% for total dissolved gases.
Spill above 15% of the total discharge was not allowed in April. Limiting discharges to
power plant capacity plus 2000 cfs in April caused May 1 reservoir elevations to exceed
May 1 flood control requirements in some years (Table 4). Simulated May 1 elevations
were above May 1 flood control elevations in 27 of 74 years for Standard FC and 16 of
74 years for VARQ. Years where simulated May 1 elevations are above flood control
requirements are shown as positive values. Drier years, which resulted in reservoir
elevations being below the VARQ flood control requirement, are shown as negative
values.

**Table 4: Differences between Hungry Horse May 1 flood control elevations and May 1 simulated
elevations due to limiting releases to power plant capacity plus 2000 cfs in April.**

Year	Amount that simulated May 1 reservoir elevation is higher than May 1 flood control requirement (ft)	
	Standard FC	VARQ
1930	+3	-16
1933	+3	+1
1934	+23	+16
1936	+2	-15
1939	+6	+3
1943	+12	+5
1946	+3	0
1947	+6	+2
1949	+1	-3
1950	+6	+1
1951	+2	+1
1952	+8	+3
1955	+1	-7
1956	+8	+1
1957	+1	-1
1959	+12	+2
1965	+10	+3
1971	+8	+2
1974	+11	+5
1980	+1	-25
1981	+2	+1
1987	+4	-5
1989	+6	+4
1990	+3	0
1991	+1	0
1997	+14	+4
2000	+1	0
Number of Years above Flood Control	27	16

For the purpose of this study, the term "spill" is designated for any release that is not used
for generation. At Hungry Horse, spill can be discharged via the spillway, outlet works,
or the turbines under speed no-load conditions. For example, if the maximum generation

capacity was 12,000 cfs and the total release was 15,000, then 3,000 cfs would be spill. Because it generates very high dissolved gas levels, spillway use is avoided whenever possible. Up to 13,680 cfs can be spilled through the outlet works at elevation 3560.0 ft. before it becomes necessary to use the spillway. Use of the spillway was not necessary under the Standard FC or VARQ simulations (1929-2002). For comparison purposes, only the days that spill exceeded 15% of the total release were considered. Past experience and observations show that spill that is under 15% of the total release ensures that the Montana State standard of 110% total dissolved gas saturation is not exceeded and recognizes that minor spills can occur without significant impacts. Spill that exceeded 15% of the total release did not occur under Standard FC and occurred for only 20 days in the 74 years examined under VARQ. The spill that occurred under VARQ was during the month May (1 day on May 31) in 1948 and during June in 1933, 1948, and 1961. These spill calculations were based on the assumption that all four generating units were available and that there were no power generation restrictions.

Hungry Horse discharges during the summer (July and August) are controlled primarily by flow augmentation for ESA listed mainstem Columbia River salmon. Inflows and the maximum volume of water available in the reservoir above elevation 3540 feet is used to compute July and August releases. Figure 11 is a duration analysis for Hungry Horse discharges (July-August). Note the similarities between Standard FC and VARQ; this is due to the comparable refill elevations between the simulations.
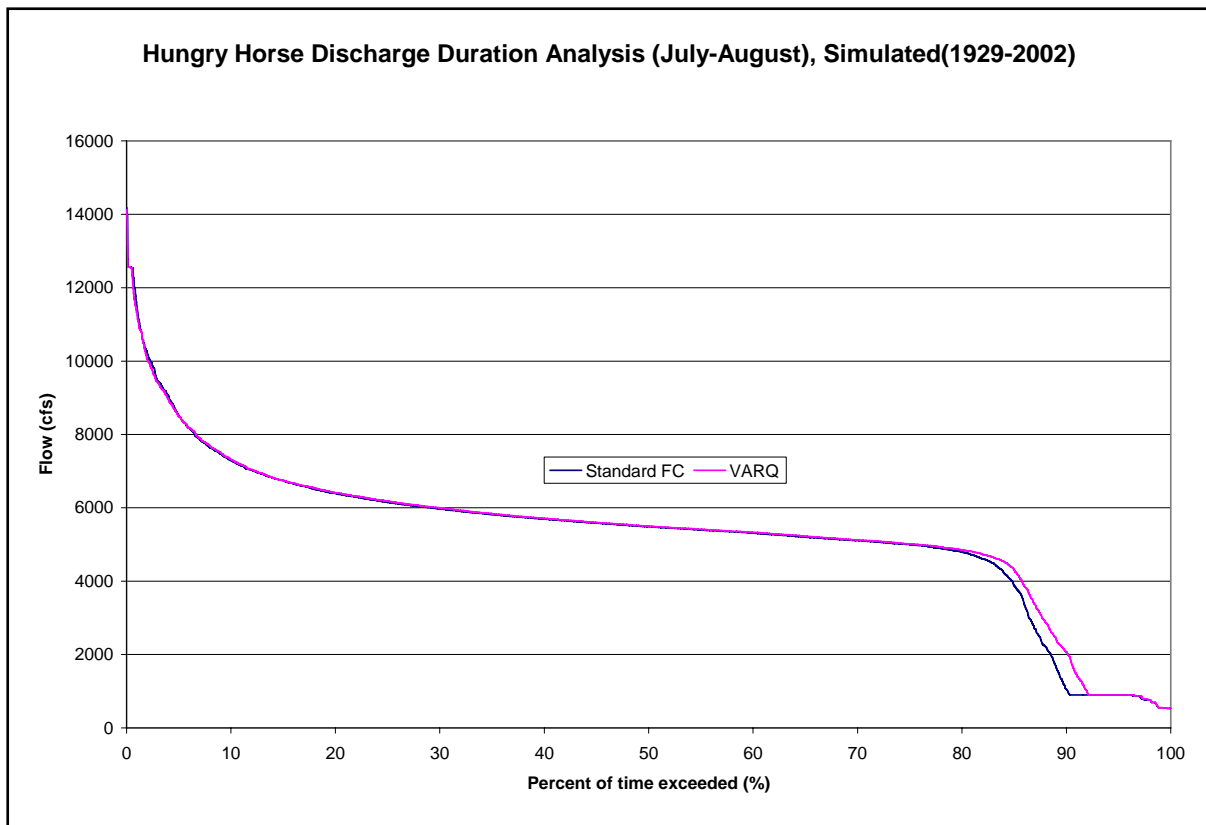

Hungry Horse Discharge Duration Analysis (July-August), Simulated(1929-2002)

Figure 11: Simulated Hungry Horse Discharge Duration Curves for July-August

Hungry Horse discharges during the fall are generally controlled by minimum flow targets which are identical for both flood control procedures. An exception is in those rare years of high fall inflows when releases need to be made in December for flood control. Releases for power can occur in the winter (January-March) and are controlled by the VDL curves. These curves allow reservoir drafts for power while still maintaining a 75% probability of reaching April 10 flood control elevations. Figures 12 and 13 show examples of power releases which occurred in 1996 in the Standard FC and VARQ simulations. Note that even though power releases draft the reservoir below the rule curve, the reservoir is at its flood control elevation by April 10.
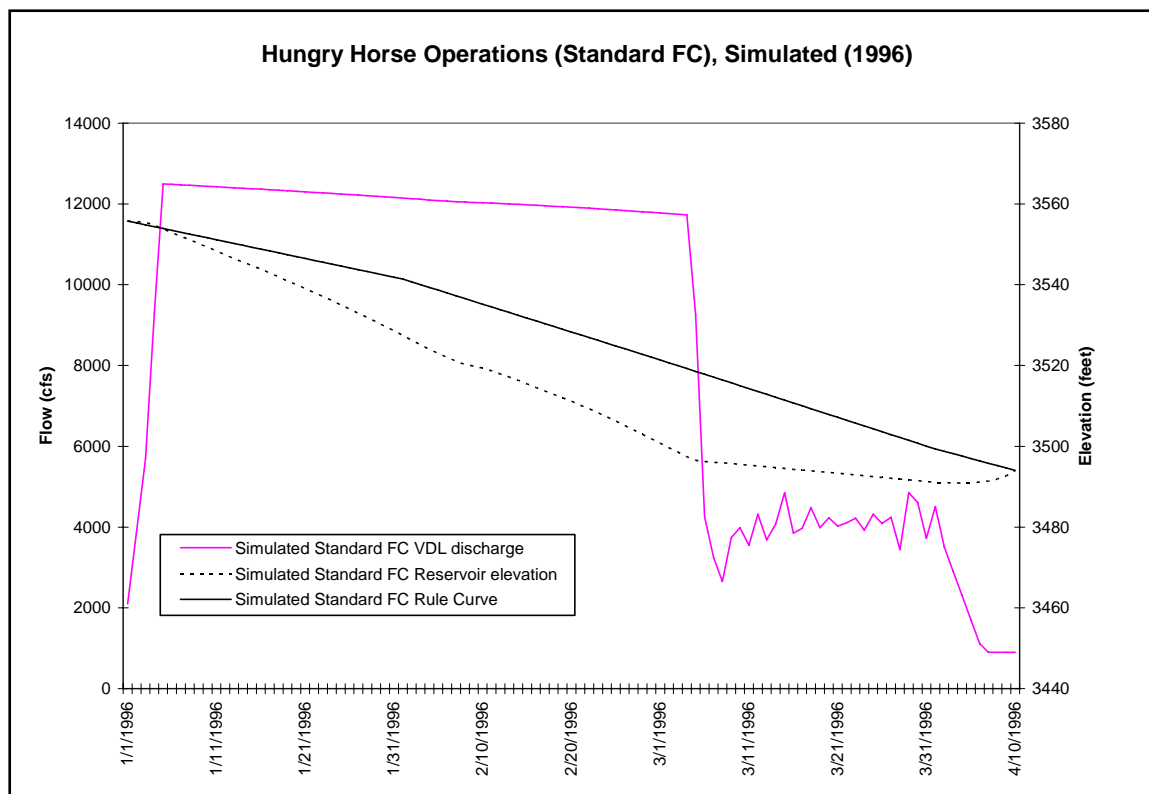

Figure 12: Simulated Hungry Horse Winter Operations (Standard FC, 1996)
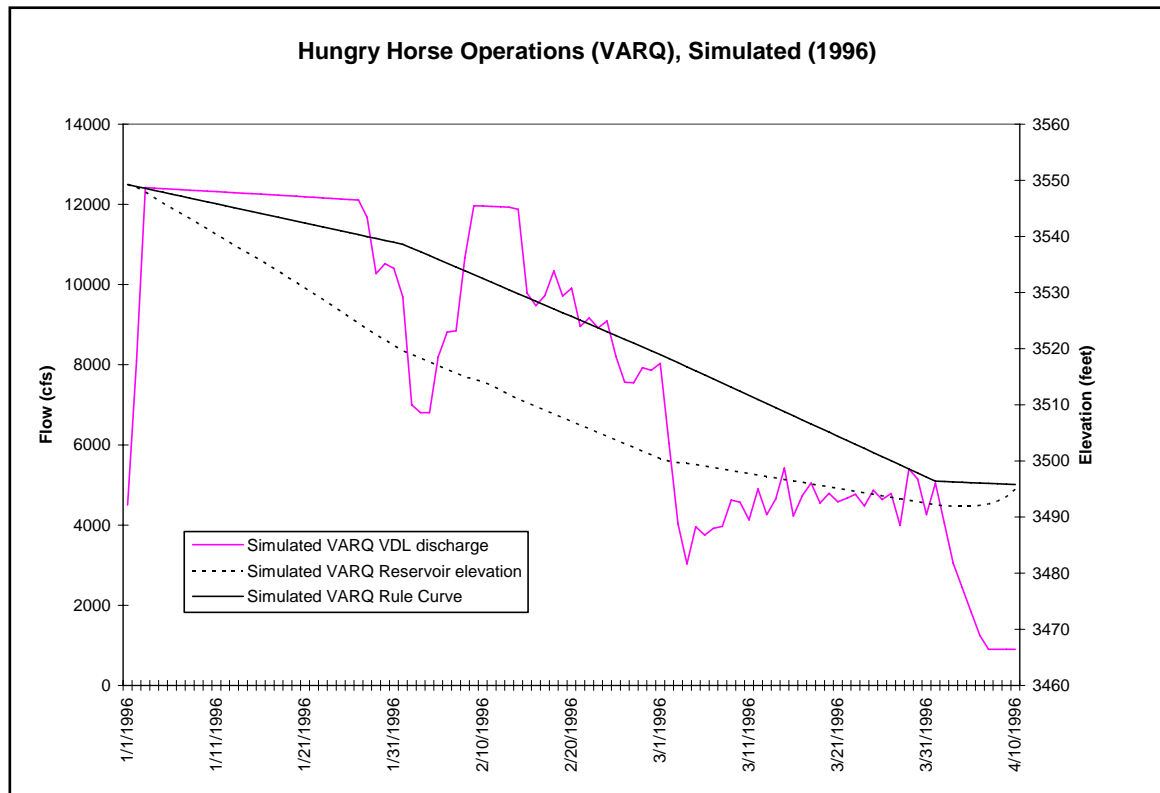
Figure 13: Simulated Hungry Horse Winter Operations (VARQ, 1996)

2.4.1.1 Generation Limitations and Total Dissolved Gas

In recent years, there has been a transmission restriction in Western Montana which has limited combined generation at Libby and Hungry Horse Dams to 900 MW. Current generation capacity is 600 MW for Libby and 428 MW for Hungry Horse for a total of 1028 MW. This transmission restriction is due in large part to the shut down of the aluminum plant at Columbia Falls, Montana (CFAC). At full operation, CFAC load is around 375 MW which is the majority of potential Hungry Horse generation. Without CFAC's load, the majority of Hungry Horse generation needs to be transmitted out of the Flathead Valley. By the summer of 2005, the limit will be raised from 900 MW to at least 944 MW due to transmission system reinforcements (Grand Coulee-Bell Project completed). Even with this increase in transmission capacity, there will still be limitations which will prevent Libby and Hungry Horse from generating at full capacity at the same time. The end result being that there could be increased releases spilled past the power plant in order to meet necessary flood control and VARQ specified releases.

Another possible generation limitation at Hungry Horse is not having four units available for generation. There are times during the year when only three units are available for generation at Hungry Horse. The fourth unit may be down for scheduled maintenance or for repair. Whatever the reason, not having four units available for generation limits total generation to a maximum of around 321 MW which may have implications on spill if required releases are above turbine capacity. It should be noted that any scheduled

maintenance tries to take into account any immediate or near future needs for the fourth unit in order to avoid spilling past the power plant.

In order to quantify the impact of these generation restrictions, two different scenarios were analyzed. In both scenarios, Hungry Horse discharges in the VARQ and Standard FC simulations were analyzed to see how much additional spill past the power plant would be required in order not to violate the generation restrictions. The scenarios examined the impact of the 944 MW Libby/Hungry Horse combined generation limitation with either four or three units available at Hungry Horse. For these scenarios, Libby elevations and discharges were obtained from the EIS modeling performed by the Corps[5]. Analysis of transmission limitations was done over the period of record of 1948-1999 because that is the time period for which the Corps simulated Libby operations. Libby generation and resultant Hungry Horse maximum generation were derived from this data.

Both scenarios were compared to the VARQ and Standard FC base case simulations (no generation restrictions). Since Hungry Horse discharges were not altered for the generation restriction scenarios, the only impact to be analyzed was spill. Figure 14 shows the total number of days that 15% spill was exceeded in a 52-year record (1948-1999) for all of the scenarios. The analysis shows only minor effects for the base case and 944 MW limit/4 unit scenarios. The largest impacts are for the three unit scenarios with spill exceeding 15% of the total release for 450 days in 34 years for VARQ and 670 days in 43 years for Standard FC. Again, the 3-unit scenario assumes only unscheduled outages. It should also be noted that in Figure 14, for the VARQ base simulation, spill occurred for 13 days in 2years. This statistic is for the period of record 1948-1999. For the period of record 1929-2002, spill occurred for 20 days in 3 years.

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[5] U.S. Army Corps of Engineers, Seattle District, "Hydrologic Analysis of Upper Columbia Alternative Operations: Local Effects of Alternatives Flood Control and Fish Operations at Libby Dam, " June 2004.
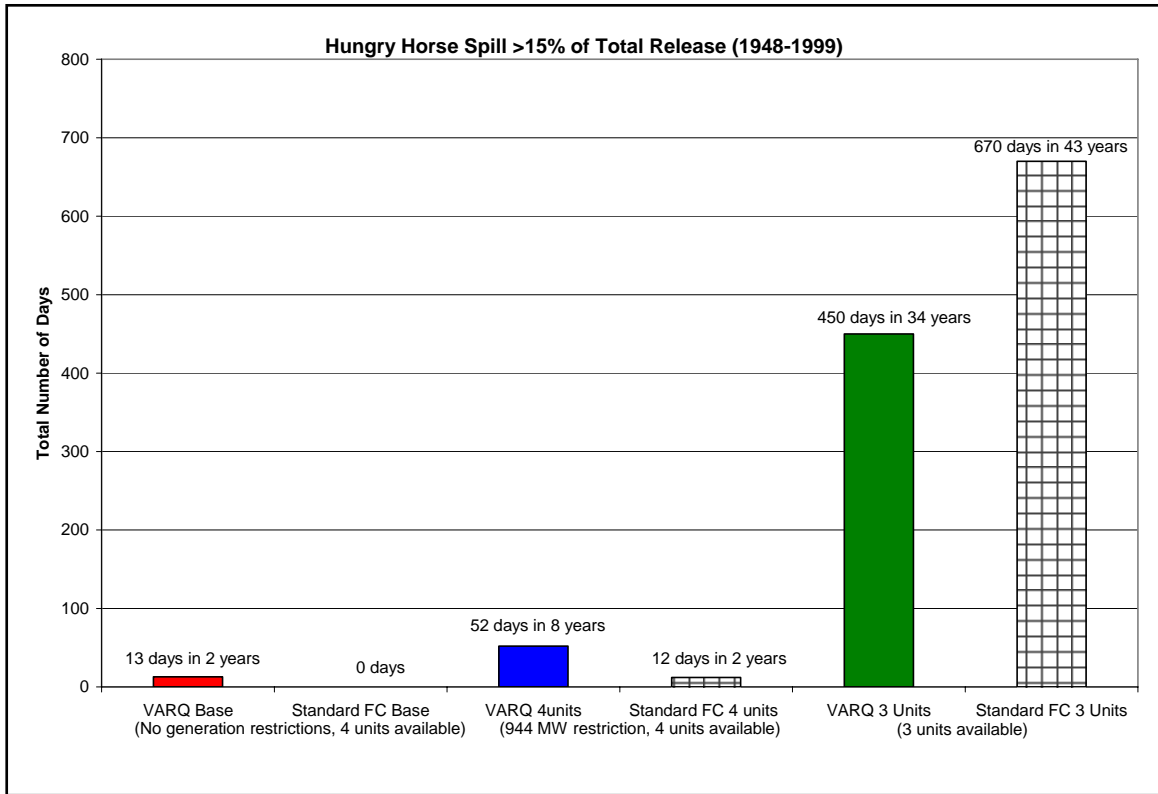
Figure 14: Hungry Horse spill for various generation restriction scenarios.

Figure 15 is a duration analysis for Hungry Horse spill (April-July) for all of the generation restriction scenarios. Once again the largest spill impacts are for the three unit scenarios, with spill exceeding 15% of the total discharge about 7 percent of the time for VARQ and 11 percent of the time for Standard FC. Also shown in Figure 15 is inset A which is a chart showing a relationship between % spill vs. % total dissolved gas saturation. Under some circumstances, high levels of total dissolved gas saturation may be harmful or lethal to fish and other aquatic organisms. This correlation used % spill and % total dissolved gas saturation that was observed in the South Fork of the Flathead River on nine different days in the winter-spring of 1996 and 1997 and in the summer of 2002. Future observations will provide more data to refine this correlation. Note that this correlation shows that spill could be as much as 20% before exceeding 110% total dissolved gases. In practice, Reclamation tries to limit Hungry Horse spill to 15% to ensure that total dissolved gas saturation is below the state of Montana's dissolved gas standard. Inset A shows that spill of 15% corresponds to around 108% total dissolved gas saturation.
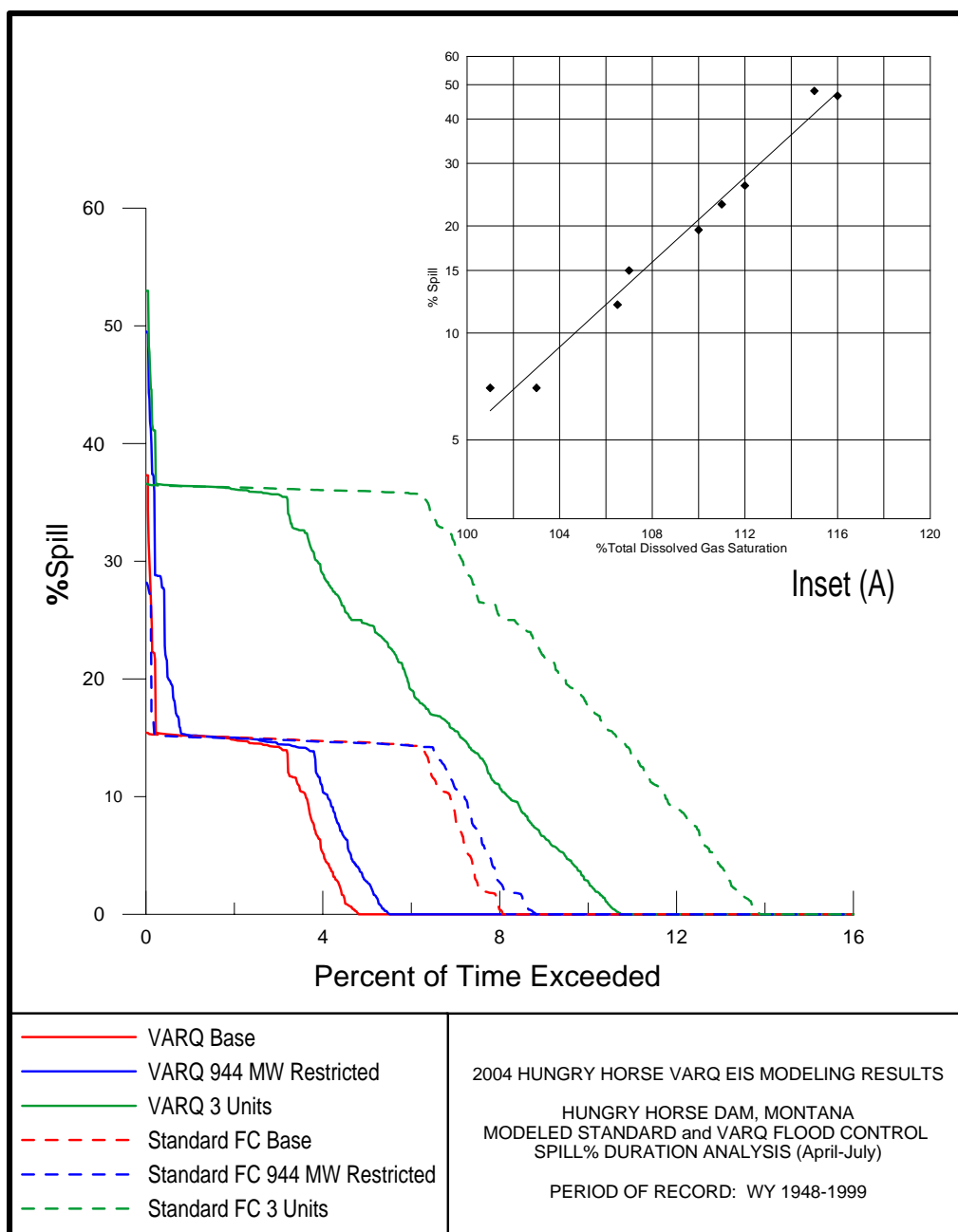
Figure 15: Hungry Horse spill duration analysis (April-July).

2.4.2 Local Flood Effects at Columbia Falls, Montana

Hungry Horse Dam is operated under Section 7 of the Flood Control Act of 1944 by the Bureau of Reclamation for flood control, in coordination with the U.S. Army Corps of Engineers. The reservoir provides flood regulation which locally benefits the flood plain from Columbia Falls to Flathead Lake and downstream to Lake Pend Oreille and Albeni Falls Dam. In addition to local flood control, Hungry Horse Reservoir provides approximately 5% of the total flood storage in the Columbia River basin for system flood control.

Columbia Falls, Montana is downstream of the confluence of the North, South, and Middle Forks of the Flathead River. Only Hungry Horse Dam on the South Fork provides flood protection. Flood stage at Columbia Falls is at 14 feet (~51,500 cfs), but there is some minor localized flooding above 13 feet (~44,500 cfs). For the Standard FC and VARQ simulations, Hungry Horse releases were decreased to 300 cfs whenever the stage at Columbia Falls exceeded 13 feet. Historically, Columbia Falls will exceed flood stage about one year in five with Hungry Horse at minimum flow. The peak 1-day flow frequency analysis for the Flathead River at Columbia Falls for the Standard FC and VARQ simulations is shown in Figure 16. A summary of the frequency analysis is shown in Table 5. Note that there is no difference in the probability of exceeding flood stage between the simulations. The stage at Columbia Falls exceeded 14 feet for a total of 35 days in 14 years for both VARQ and Standard FC. Below flood stage, flows are slightly higher for VARQ. The flow frequency analysis covers the simulation period of record (1929-2002) excluding 1964. 1964 is considered an extreme outlier event which has been assigned an exceedance probability of 0.05% based on an analysis discussed in a Memorandum for Record[6] written by the Corps in 1979. The plotting position for the 1964 flood (0.05%) is included as a separate point in the plot. There is no difference between the simulations for this event since Hungry Horse Reservoir contained the South Fork's flows and was releasing only 300 cfs for both VARQ and Standard FC at the time of the flood.

Table 5: Peak 1-day flow frequency analysis for the Flathead River at Columbia Falls[7].

Exceedance Frequency (%)[a]	Flow (cfs)		Stage (ft)		Flow Difference (cfs)	Stage Difference (ft)
	Standard FC	VARQ	Standard FC	VARQ		
1	71,800	71,800	16.5	16.5	0	0.0
2	68,600	68,600	16.1	16.1	0	0.0
5	61,800	61,800	15.3	15.3	0	0.0
10	56,900	56,900	14.7	14.7	0	0.0
18	**51,500**	**51,500**	**14.0**	**14.0**	**0**	**0.0**
20	48,800	50,200	13.6	13.8	1,400	0.2
30	44,600	44,800	13.0	13.0	200	0.0
40	44,600	44,600	13.0	13.0	0	0.0
50	43,600	44,600	12.8	13.0	1,000	0.1
70	38,500	42,100	12.1	12.6	3,600	0.6
90	28,000	29,700	10.2	10.6	1,700	0.3
99	16,600	16,600	7.8	7.8	0	0.0
[a] Probability of exceeding a given flow or stage in any given year						

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[6] Memorandum for Record, U.S. Army Corps of Engineers, Chief, Hydrology & Hydraulics Branch, Seattle District, Seattle, Washington, "Flood-Frequency Determination for the Flathead River at Columbia Falls, Montana – Joint Memo for Agreement Between U.S. Geological Survey and U.S. Army Corps of Engineers", September 1979.

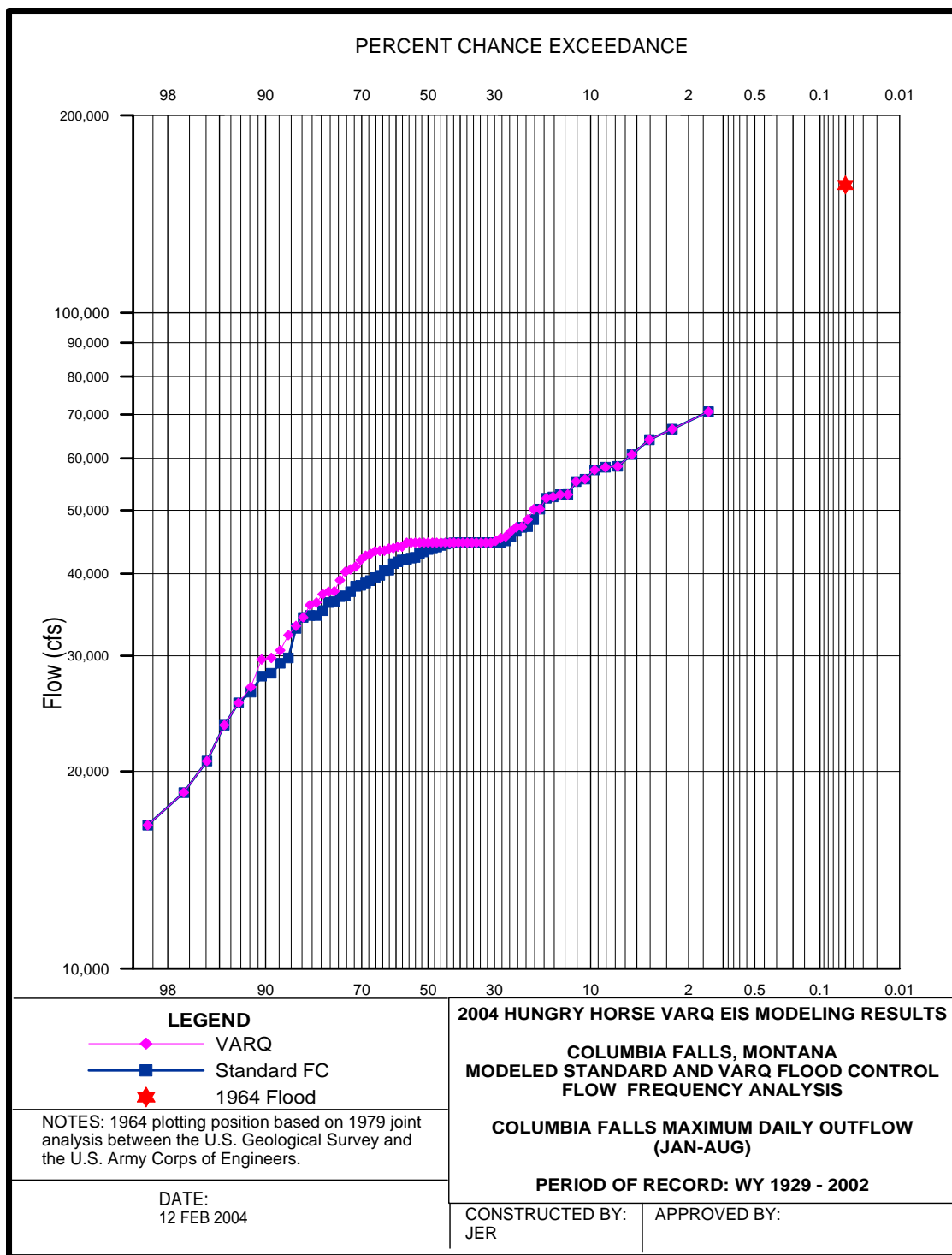[7] Flows based on U.S. Geological Survey rating table as of August, 2002.

Figure 16: **Peak 1-day flow frequency curves for the Flathead River at Columbia Falls.**

2.4.3 Effects at Kerr Dam and Flathead Lake

The differences in Hungry Horse discharges between Standard FC and VARQ have subsequent effects in the operation of Kerr Dam on Flathead Lake. For the purpose of

modeling these effects at Kerr Dam, the following guidelines and assumptions were
followed in the simulations:

1) Flood control requirements were followed in accordance with a 1962
    Memorandum of Understanding (MOU) between the Kerr Dam licensee and
    Corps. The required April 15 flood control elevation of 2883.0 feet was modified,
    if applicable, during drought years to allow for a higher April 15 flood control
    elevation. This would help Flathead Lake fill in dry years and still maintain
    minimum flow requirements below Kerr Dam without jeopardizing flood control.
    Kerr Dam is currently operating under an "Interim Drought Management Plan"
    during drought years which includes this type of operation.

2) Minimum flows below Kerr Dam are in accordance with Article 56 of its Federal
    Energy Regulatory Commission (FERC) license. Table 6 shows the minimum
    flow requirements below Kerr Dam.

Table 6: Minimum flow requirements below Kerr Dam

Dates	Minimum Flow (cfs)	Ramped to	Daily Ramp Increment (cfs/day)
August 1 to April 15	3,200		
April 16 to April 30	3,200	5,000	120
May 1 to May 15	5,000	12,700	513
May 16 to June 30	12,700		
July 1 to July 15	12,700	6,400	-420
July 16 to July 31	6,400	3,200	-200

3) Maximum discharges are limited by the natural lake and channel configurations.

4) Discharge ramping rates were adhered to.

Differences in Standard FC and VARQ affect the timing and magnitude of Hungry Horse
discharges which in turn affect operations at Kerr Dam and Flathead Lake. As mentioned
in the Hungry Horse effects section, Hungry Horse discharges are generally lower in
April and higher in May and June for VARQ. Since Flathead Lake is usually drafting
during the first half of April to its flood control elevation of 2883.0 feet, flows from
Hungry Horse are being passed through Flathead Lake. Conversely, the higher Hungry
Horse discharges in May and June under VARQ can be stored in Flathead Lake during
the refill period. The end result is Flathead Lake has a slightly better probability of
filling to elevation 2893.0 feet while still meeting minimum flow requirements below
Kerr Dam. Figure 17 shows the probability that Flathead Lake will fill to a certain
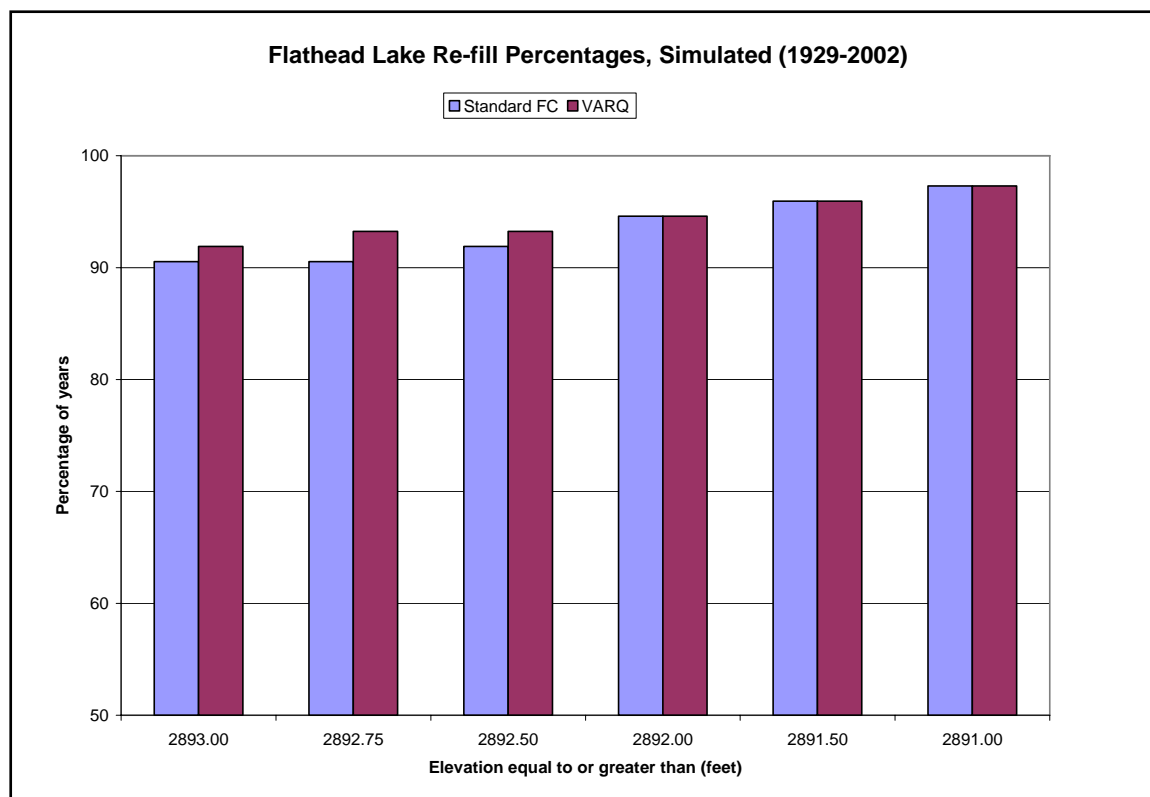elevation for both Standard FC and VARQ.

Figure 17: Flathead Lake Refill Percentages.

It is desirable to maintain Flathead Lake full (El. 2893.0) throughout the summer for recreational purposes without jeopardizing the minimum flow requirement. Figure 18 shows the duration curves for Flathead Lake elevation from June 15 – August 31 for Standard FC and VARQ. Flathead Lake has a slightly better probability of being near full under VARQ.
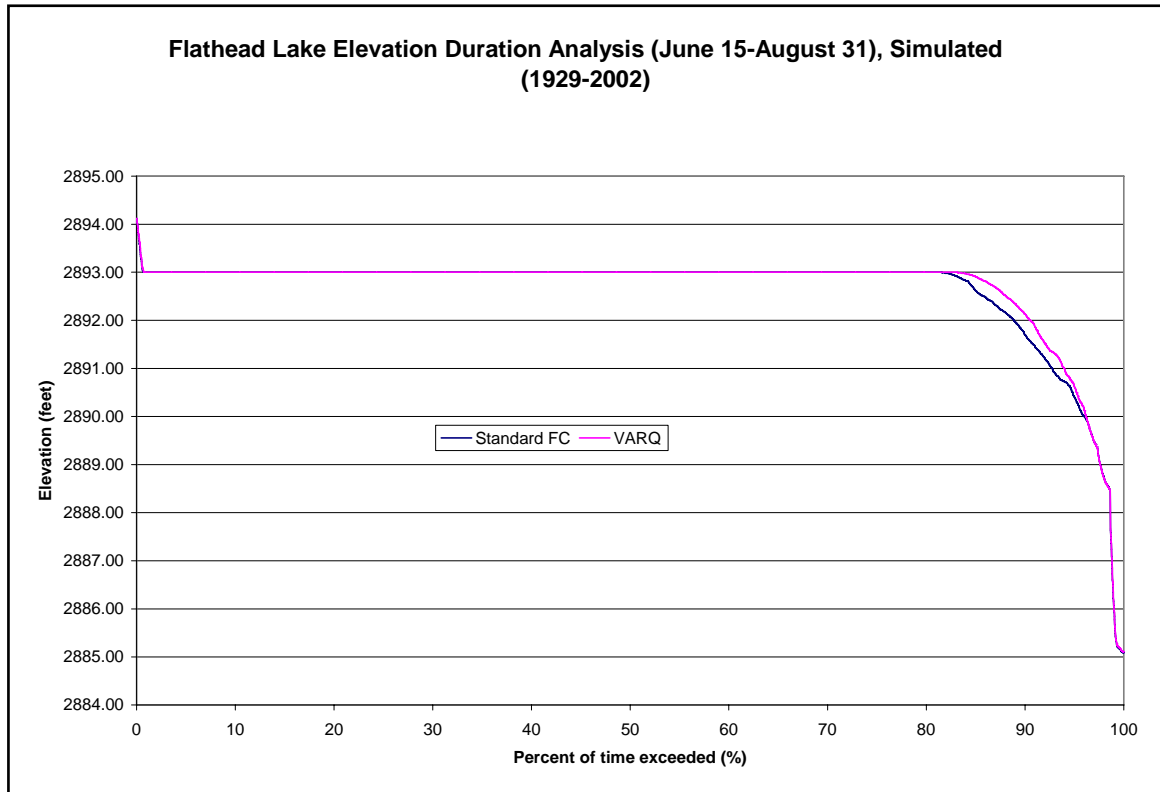

Figure 18: Elevation Duration Analysis at Flathead Lake (June 15 – August 31).

There are minor discharge differences between VARQ and Standard FC at Kerr Dam. The higher Hungry Horse releases in May and June and the lower releases in April for VARQ create a similar effect on the discharges at Kerr Dam. Figure 19 shows average monthly discharges from Kerr Dam. Flows are slightly higher in May and June and lower in January, February, and April under VARQ.
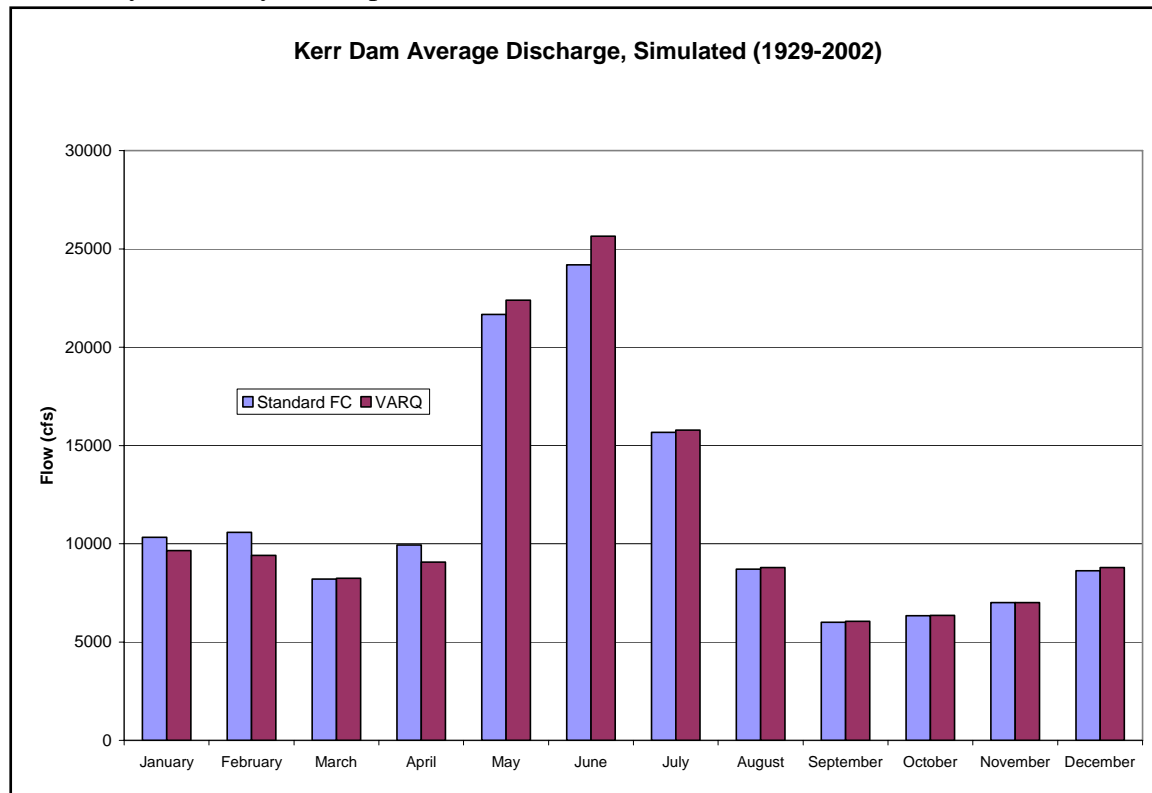

Figure 19: Kerr Dam Average Monthly Discharges.

Peak discharges below Kerr Dam were also analyzed for the VARQ and Standard FC simulations. The peak 1-day flow frequency analysis for the Flathead River below Kerr Dam is shown in Figure 20. There are only minor differences between Standard FC and VARQ.
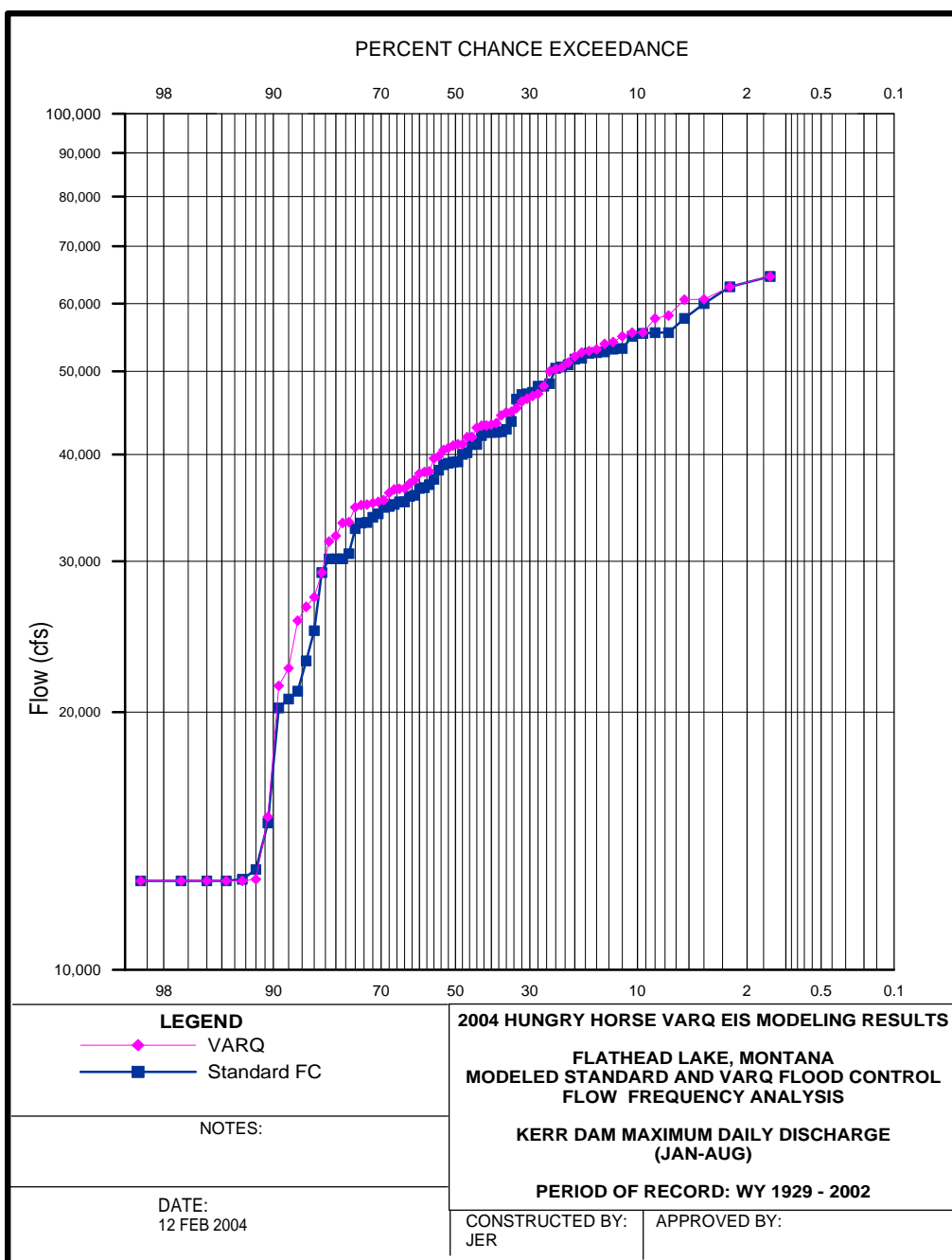
Figure 20: Peak 1-day flow frequency curves for the Flathead River below Kerr Dam.

There is evidence to show that flooding can occur above Flathead Lake along the southern portion of the Flathead plain during times when Flathead Lake elevation in combination with flow at Columbia Falls reaches a certain level.[8] Flooding can occur when Flathead Lake is at or above elevation 2893 feet and flows at Columbia Falls

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[8] Based on Corps nomograph chart No. 4515 dated 2-4-1947, "Non-damaging Flow Flathead River at Columbia Falls, Montana"

exceed 48,000 cfs. In the simulations, Flathead Lake was above elevation 2893 feet and Columbia Falls flow exceeded 48,000 cfs 16 times in 4 years for Standard FC and 31 times in 7 years for VARQ. All instances occurred in June and amounted to 0.7% of the total days in June for Standard FC and 1.4% of the total days in June for VARQ.

2.4.4 Effects at Albeni Falls Dam and Pend Oreille Lake.

VARQ effects on Lake elevations and releases were analyzed at Albeni Falls Dam. For the purpose of modeling these effects at Albeni Falls Dam, the following guidelines and assumptions were followed in the simulations:

1) Target elevations for Pend Oreille Lake include flood control elevations, winter target elevations, and summer normal operating elevations. For this analysis, two different winter target elevations were used for Pend Oreille Lake. One analysis looked at a winter target elevation of 2055.0 feet for the period of record (1929-2002). Another analysis looked at elevation 2051.0 feet for a winter target elevation.

2) Minimum release below Albeni Falls Dam is 4,000 cfs.

3) Maximum discharges are limited by the natural lake and channel configurations.

4) Discharge ramping rates limited to 10,000 cfs/day.

2.4.4.1 Winter Target Elevation (2055.0 feet)

VARQ operations at Hungry Horse had a negligible effect on the summer operating elevation of 2062.5 feet or the winter target elevation of 2055.0 feet at Pend Oreille Lake. This is evidenced by the elevation duration curves shown in Figures 21 and 22.
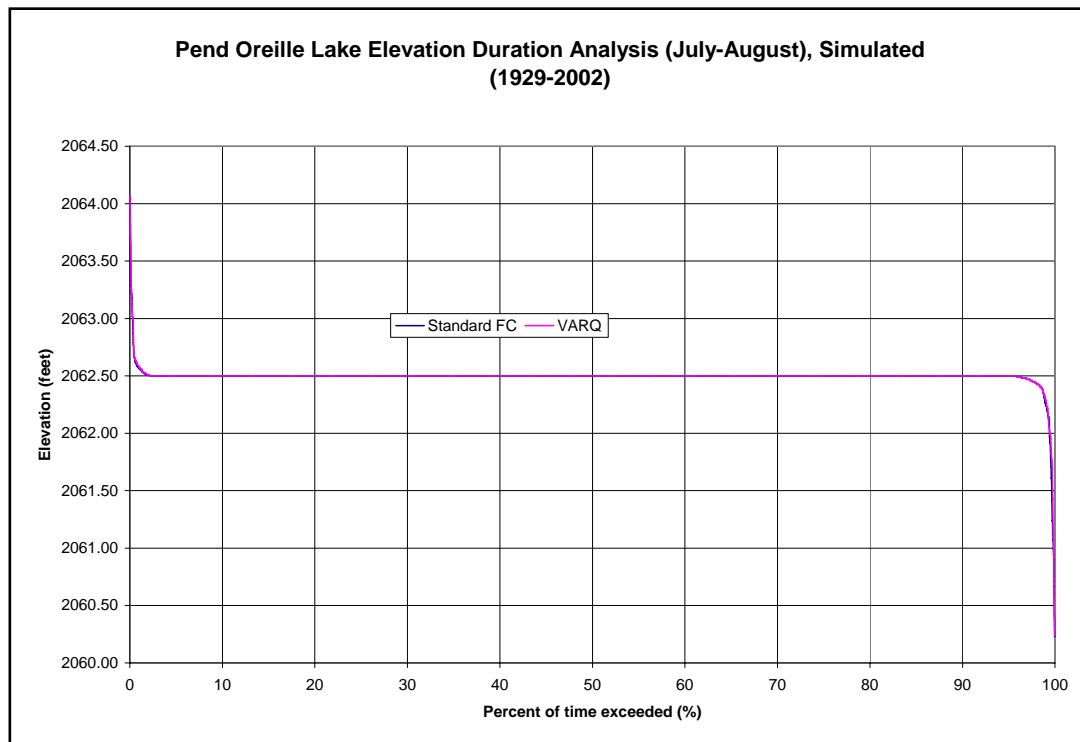
Figure 21: Elevation Duration Analysis at Pend Oreille Lake for July – August (winter target el. 2055 ft.).
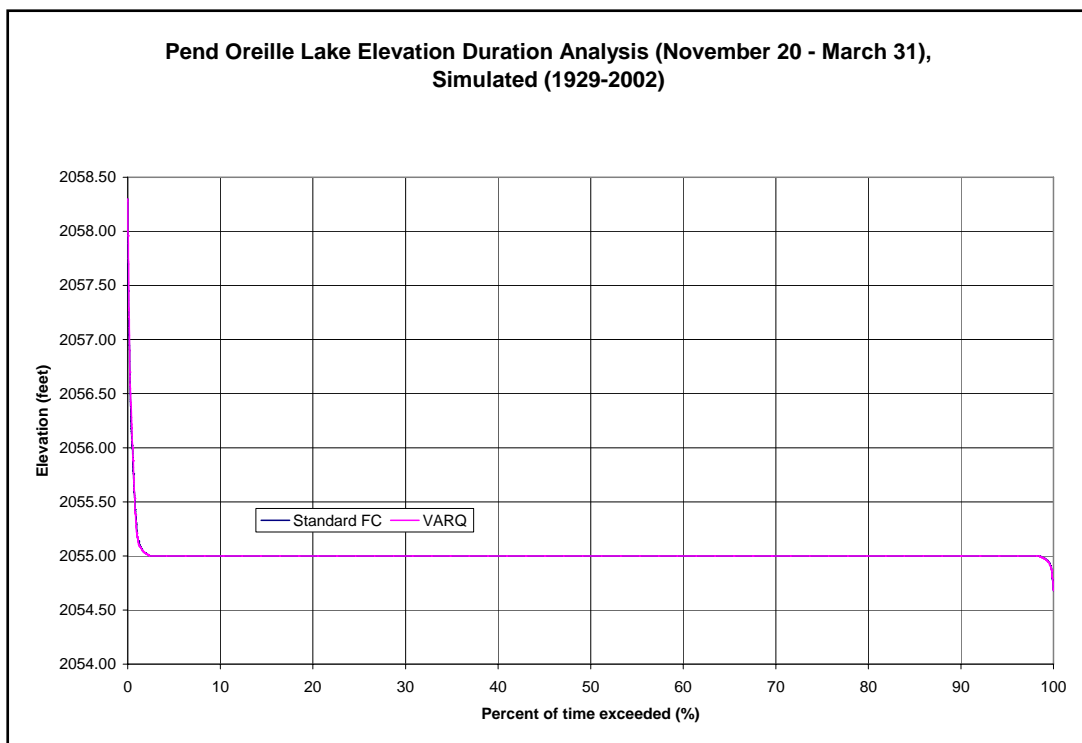

Figure 22: Elevation Duration Analysis at Pend Oreille Lake for November 20 - March 31 (winter target el. 2055 ft.).

Average Albeni Falls discharges are slightly higher in June and lower in January, February, and April for VARQ. Figure 23 shows average monthly discharges for Albeni Falls Dam.
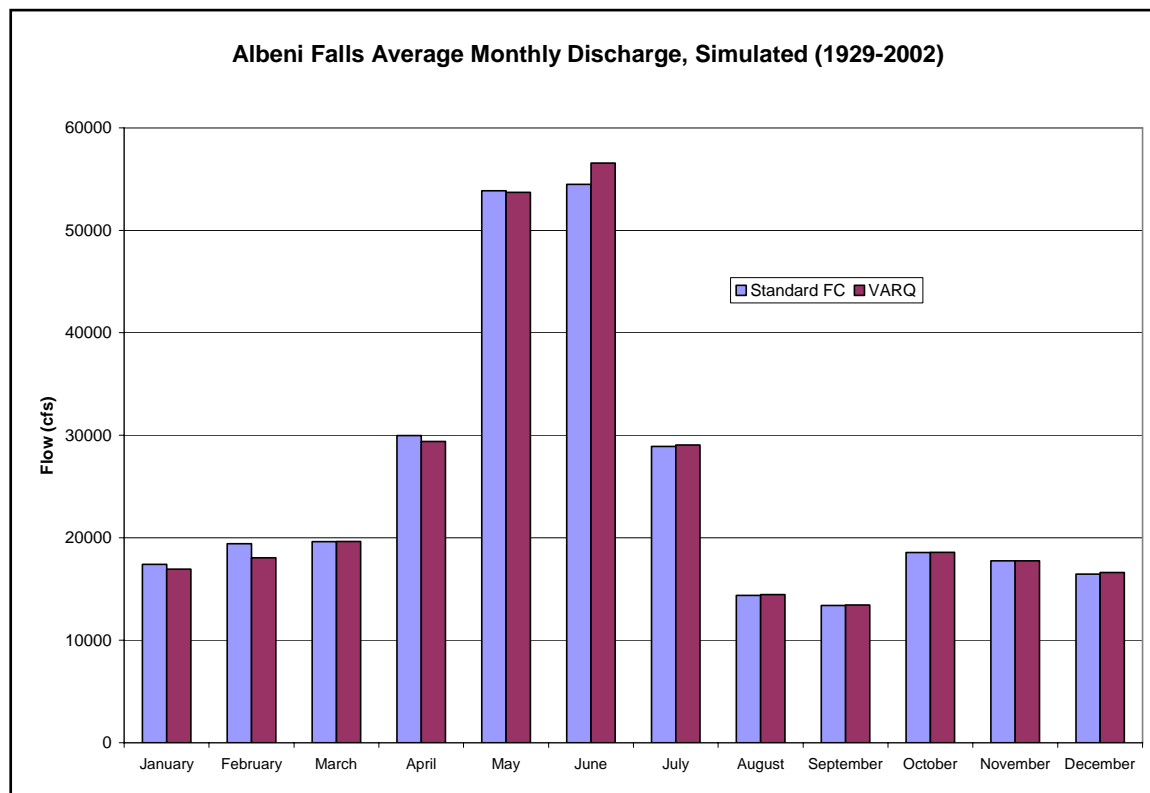

Figure 23: Albeni Falls Dam Average Monthly Discharges (winter target el. 2055 ft.)

The area below Albeni Falls Dam can be impacted by two types of flooding: 1) agricultural flooding in March and April as a result of early spring runoff from Calispell and Trimble Creeks and 2) flooding in June due to high flows in the Pend Oreille River from high elevation snowmelt.

The agricultural flooding in the Cusick, Washington area is due to a combination of early spring runoff from Calispell and Trimble Creeks and high river levels due to the operation of Box Canyon and Albeni Falls Dams. Farmers near Cusick may have problems draining their fields in late March and April when Calispell and Trimble Creeks are running high. Pend Oreille PUD operates Box Canyon Dam and pumping facilities at the mouth of the creeks to minimize backwater effects on agricultural lands.

Problems with flooding can occur at Cusick, Washington if flows in excess of 43,000 cfs are passed through Lake Pend Oreille[9]. Figure 24 is a duration analysis for Albeni Falls

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[9] U.S. Army Corps of Engineers, Seattle District, Seattle, Washington, "Analysis of the Kokanee Experiment at Lake Pend Oreille on Water Levels in the Cusick, Washington Area", September 1999.

discharges (March-April). Flows below Albeni Falls Dam are slightly lower with VARQ. Flows exceed 43,000 cfs about 9% of the time for VARQ and about 10% of the time for Standard FC during the period March 1-April 30. In relation to the field drainage issue, this is the period of most concern to farmers near Cusick.
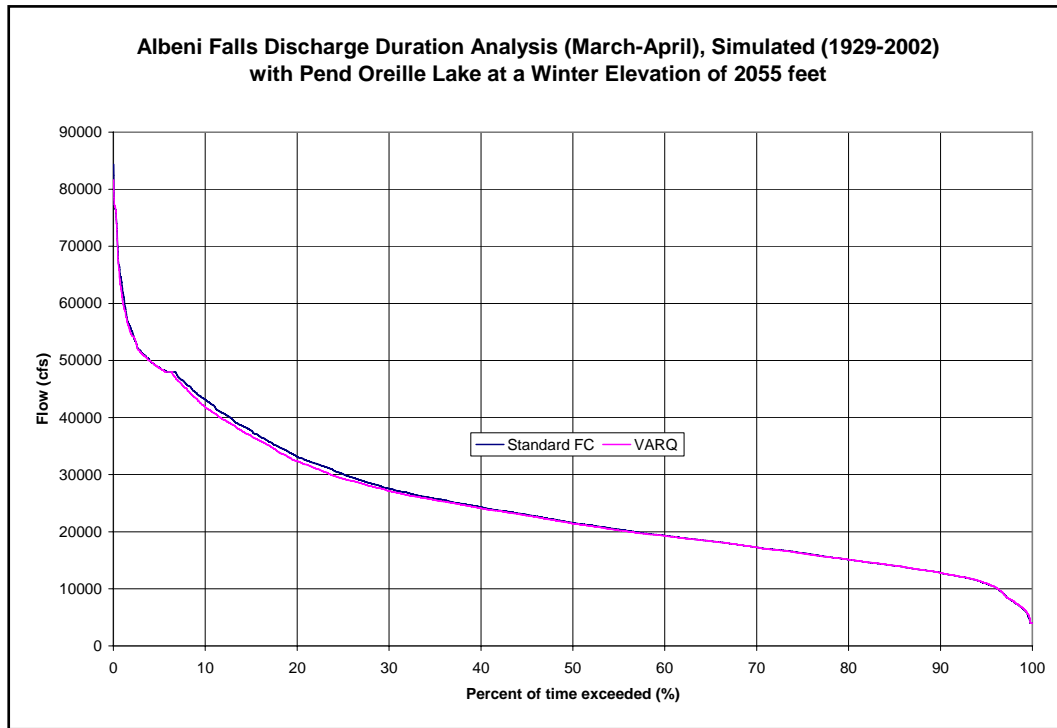

Albeni Falls Discharge Duration Analysis (March-April), Simulated (1929-2002) with Pend Oreille Lake at a Winter Elevation of 2055 feet

Figure 24: Simulated Albeni Falls Discharge Duration Curves for March-April (winter target el. 2055 ft.)

Figure 25 is a duration analysis for Albeni Falls discharges (May-June). Flows are slightly higher for VARQ when compared to Standard FC.
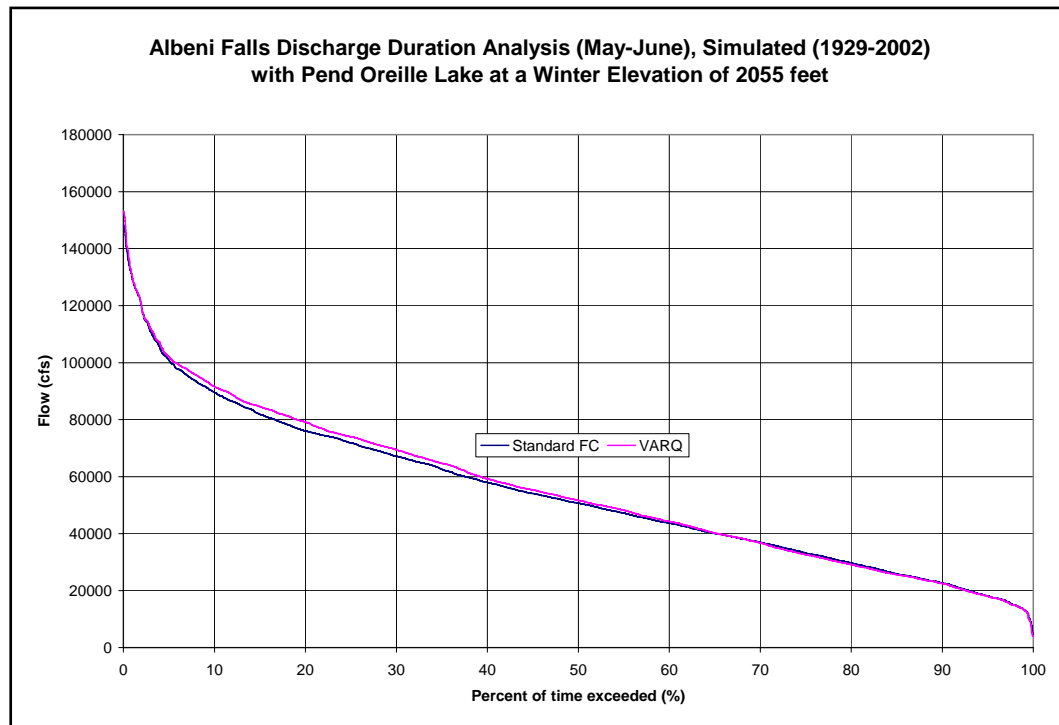

Figure 25: Simulated Albeni Falls Discharge Duration Curves for May-June (winter target el. 2055 ft.)

Flooding below Albeni Falls Dam in June is due to spring snowmelt, and is a relatively common occurrence happening historically about one year in four. The National Weather Service issues flood warnings when the releases from Albeni Falls Dam are expected to exceed 100,000 cfs. The peak 1-day flow frequency analysis for the Pend Oreille River below Albeni Falls Dam is shown in Figure 26 for the Standard FC and VARQ simulations. No significant differences exist between the two flood control simulations when comparing years with peak flows above flood stage. The annual peak flow exceeded 100,000 cfs about 27% of the time for both Standard FC and VARQ.
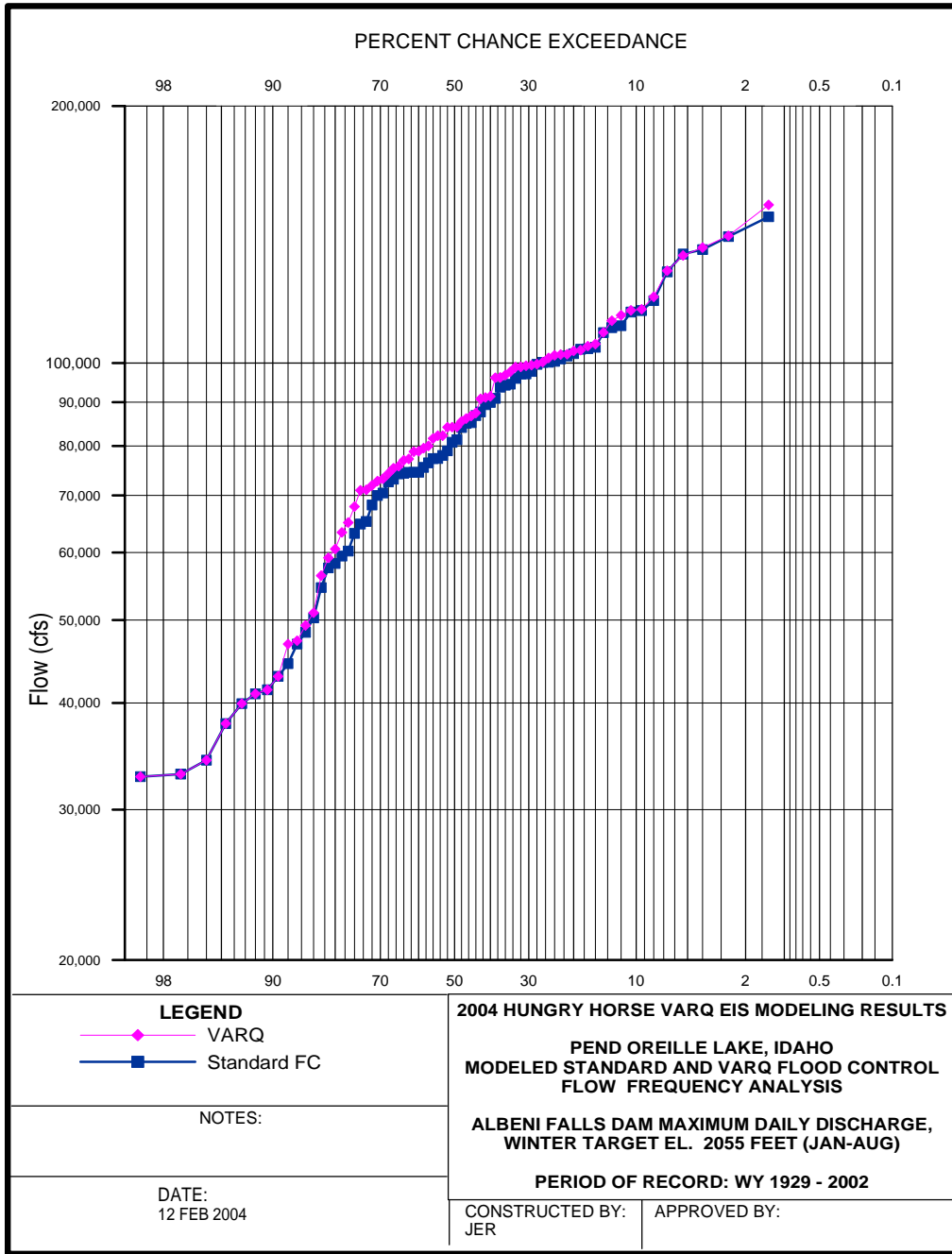

Figure 26: Peak 1-day flow frequency curves for the Pend Oreille River below Albeni Falls Dam (winter target el. 2055 ft.)

2.4.4.2 Winter Target Elevation (2051.0 feet)

At elevation 2051 feet Pend Oreille Lake has 353,000 acre-feet more space than at elevation 2055 feet. VARQ operations at Hungry Horse had a negligible effect on the summer operating elevation of 2062.5 feet or the winter target elevation of 2051feet at Pend Oreille Lake. This is evidenced by the elevation duration curves shown in Figures 27 and 28.
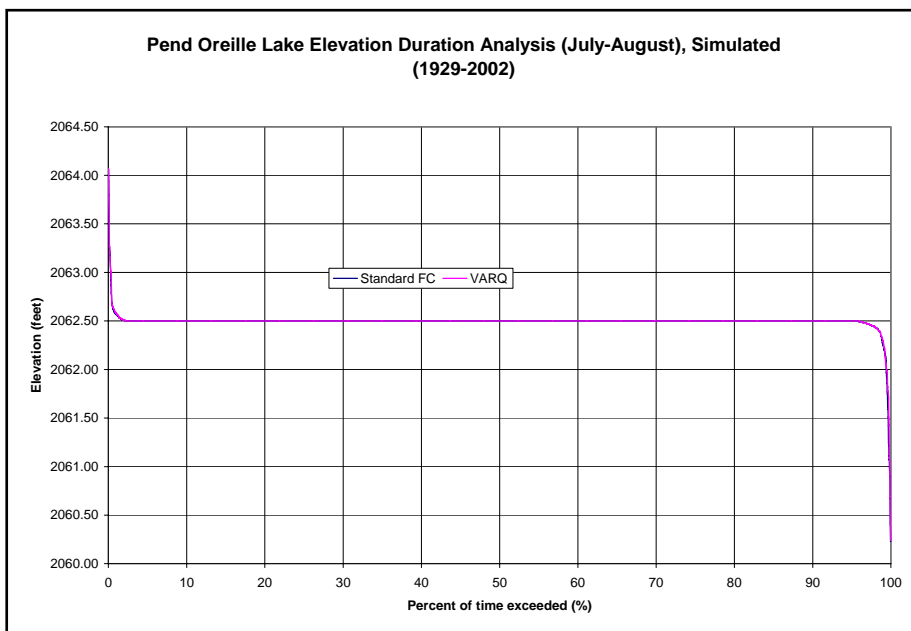

Figure 27: Elevation Duration Analysis at Pend Oreille Lake for July – August (winter target el. 2051 ft.).
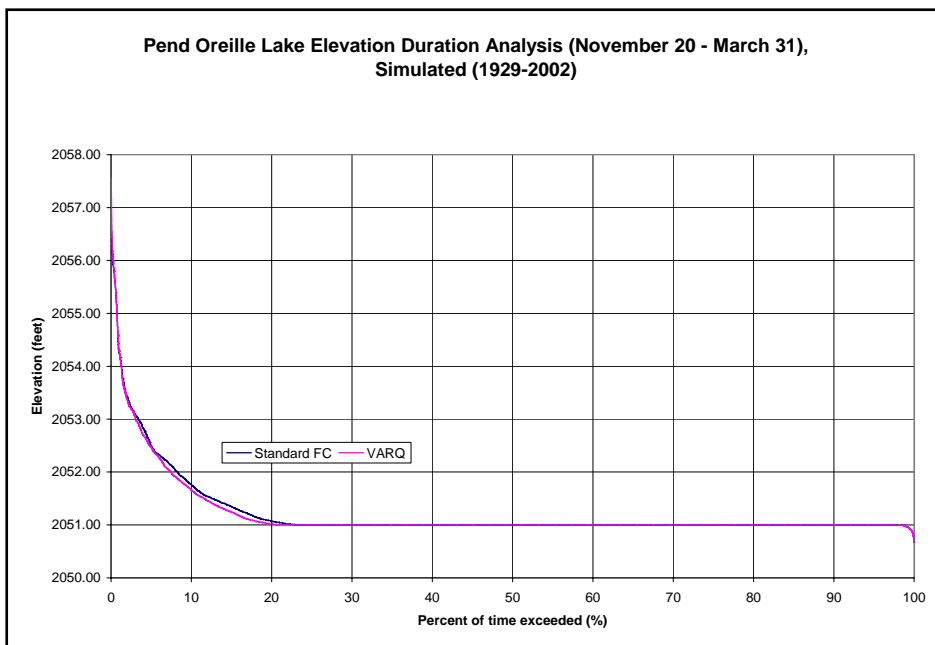

Figure 28: Elevation Duration Analysis at Pend Oreille Lake for November 20 - March 31 (winter target el. 2051 ft.).

Average monthly discharges are shown in Figure 29. Discharges are slightly higher in June and lower in January, February, and April for VARQ. Comparing to the simulations using a winter target elevation of 2055 feet, the only monthly differences occur in April and November.
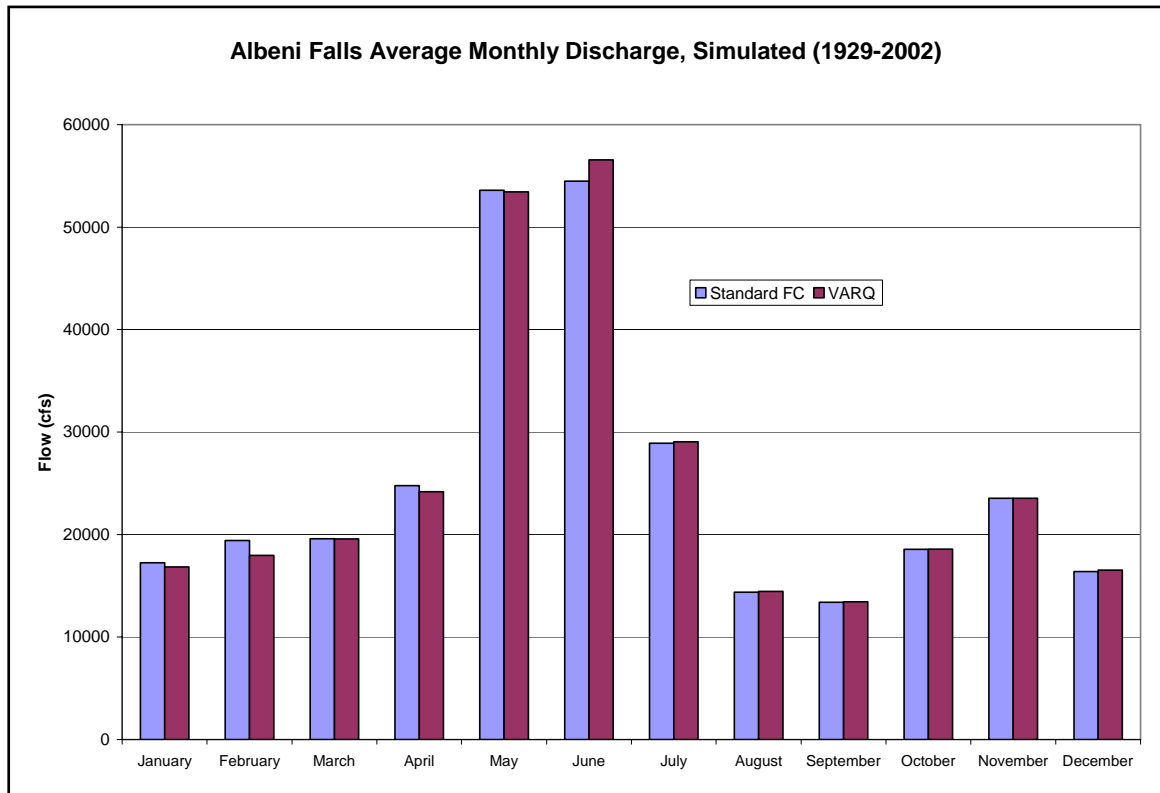

Figure 29: Albeni Falls Dam Average Monthly Discharges (winter target el. 2051 ft.)

Figure 30 is a duration analysis for Albeni Falls discharges (March-April). Flows below Albeni Falls Dam are slightly lower when comparing VARQ to Standard FC. Flows exceed 43,000 cfs about 6% of the time for both VARQ and Standard FC during the period March 1-April 30. The duration analysis for Albeni Falls discharges (March-April) is also shown for a winter target elevation of 2055.0 feet (for Pend Oreille Lake) on the same graph. This comparison shows that there is a noticeable effect on Albeni Falls March-April discharges between the two different winter target elevations. The extra four feet of space, in the winter target of 2051.0 feet analysis, translated into decreased flows during March and April. The difference between VARQ and Standard FC is insignificant in either winter target scenario.
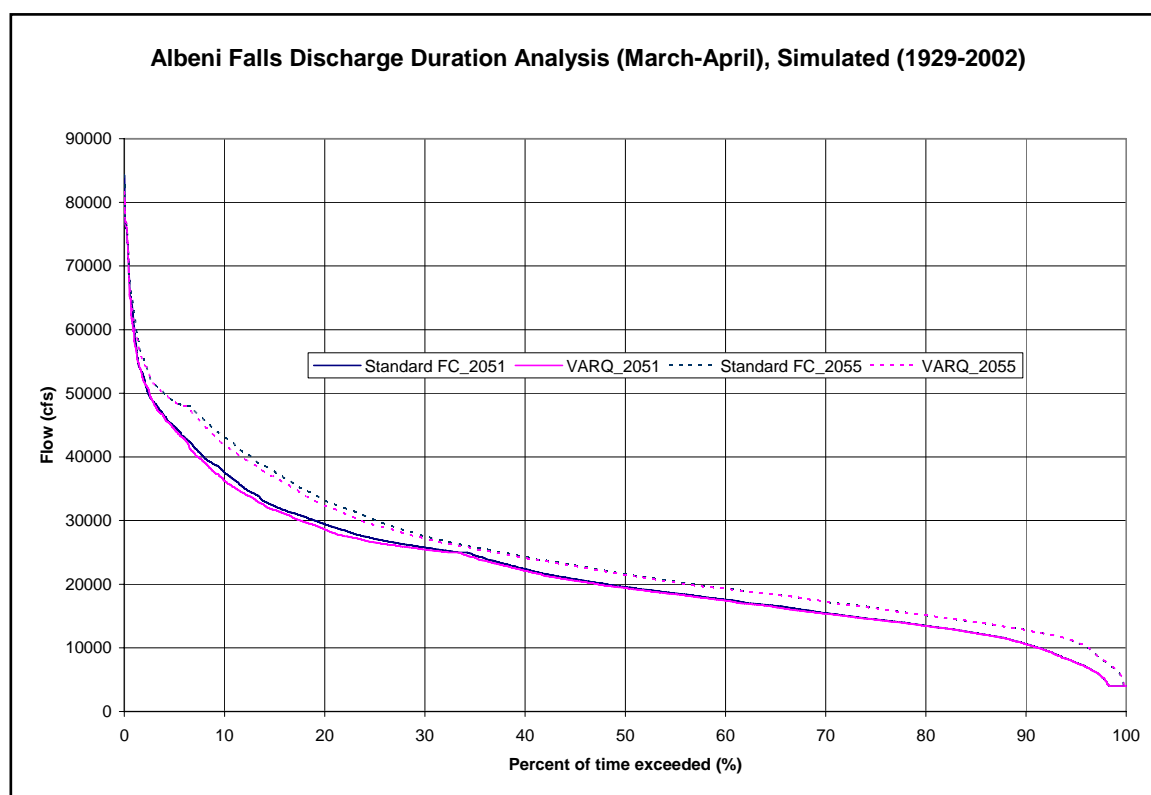

Figure 30: Simulated Albeni Falls Discharge Duration Curves for March – April, Both winter target elevations of 2051.0 feet and 2055.0 feet are shown.

Figure 31 is a duration analysis for Albeni Falls discharges (May-June) for the winter target elevation of 2051 feet. Flows are slightly higher for VARQ when compared to Standard FC. Results using a winter target elevation of 2055 feet (Figure 25) were essentially the same and are therefore not compared here.
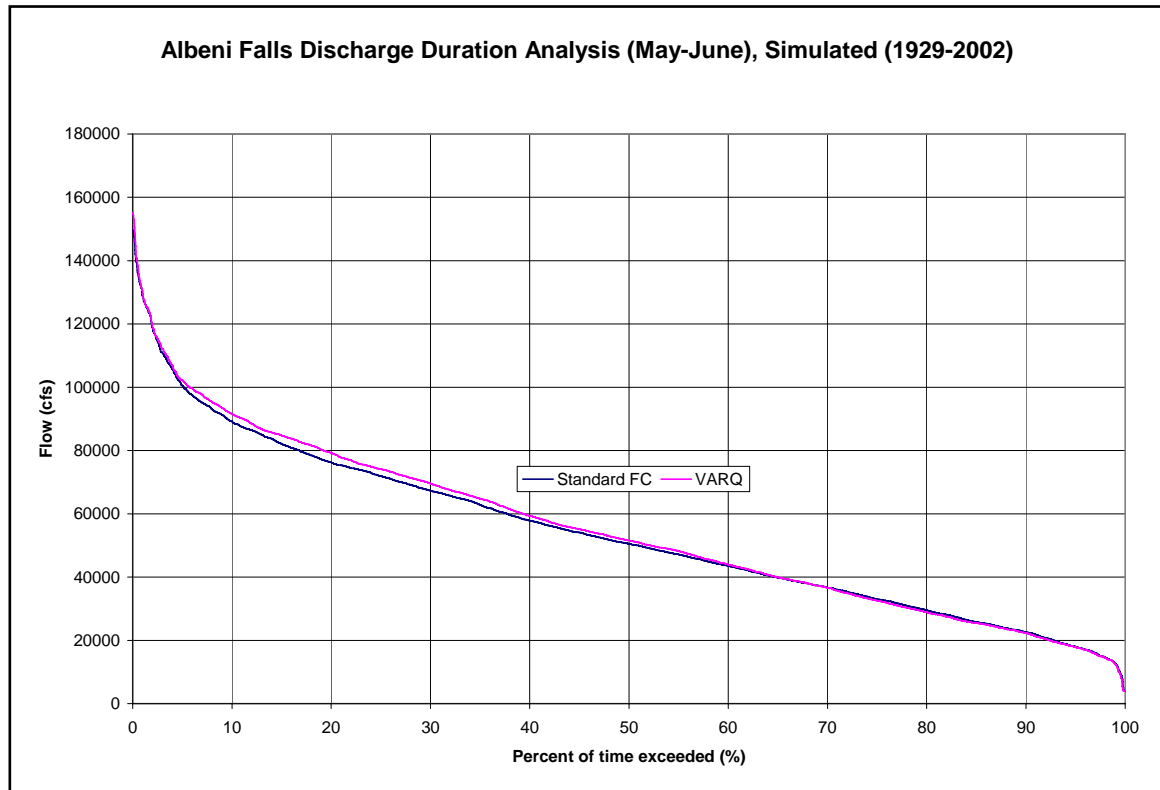

Figure 31: Simulated Albeni Falls Discharge Duration Curves for May-June (winter target el. 2051 ft.)

The peak 1-day flow frequency analysis for the Pend Oreille River below Albeni Falls Dam is shown in Figure 32 for the Standard FC and VARQ simulations. No significant differences exist between the two flood control simulations when comparing years with peak flows above flood stage. The annual peak flow exceeded 100,000 cfs about 27% of the time for both Standard FC and VARQ, which is essentially the same result as in target elevation of 2055 feet (see Figure 24).
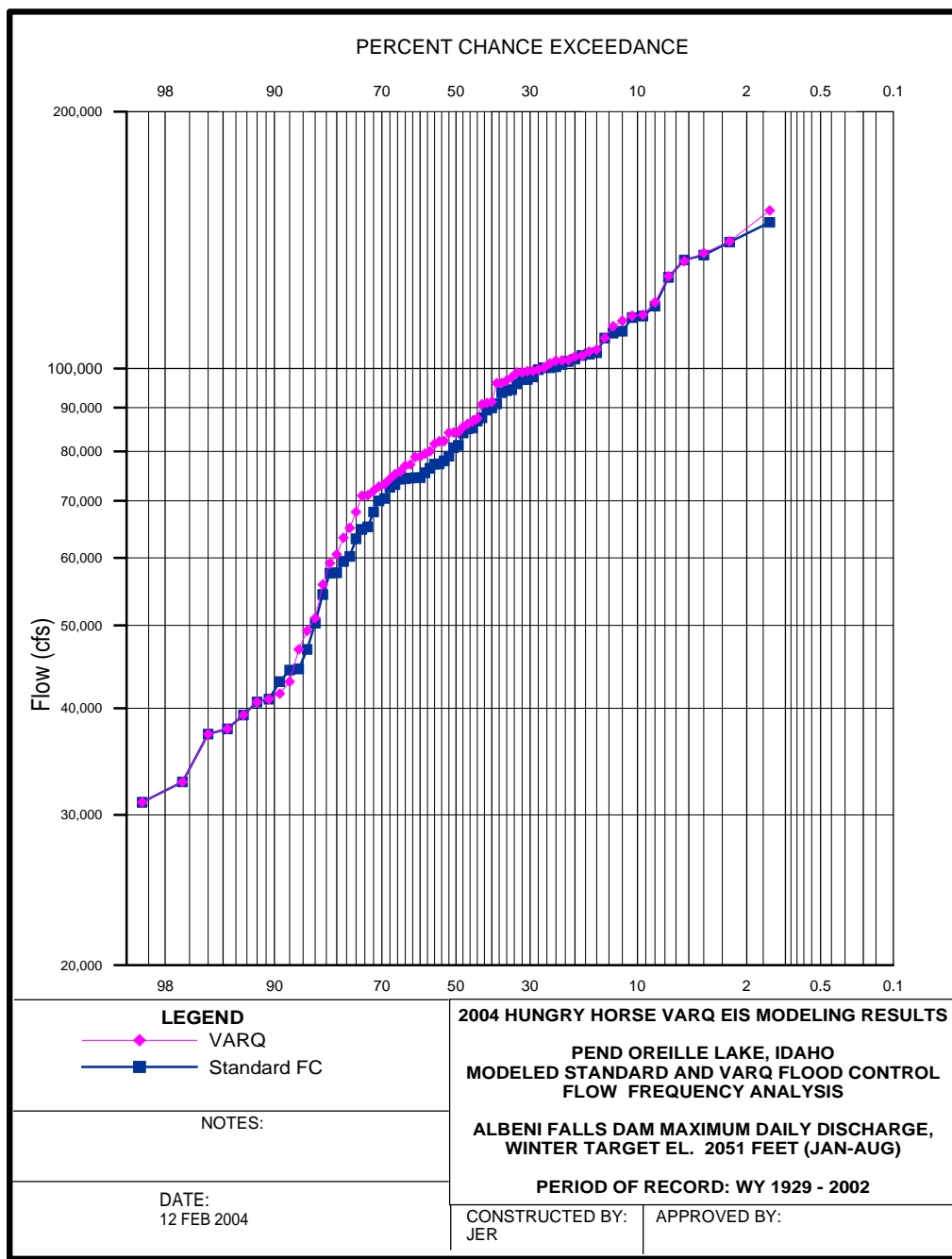

Figure 32: Peak 1-day flow frequency curves for the Pend Oreille River below Albeni Falls Dam (winter target el. 2051 ft.)

3.0 Summary

The hydrologic analysis of the VARQ flood control plan at Hungry Horse Dam has
shown that there are only small impacts to reservoir elevations and river flows when
compared to the Standard flood control plan. This is true not only at Hungry Horse
Reservoir but also at all points from Hungry Horse Dam downstream to the Pend Oreille
River below Albeni Falls Dam.

Refill probabilities are slightly higher at Hungry Horse Reservoir and at Flathead Lake
under VARQ. Flathead Lake also can stay full a little longer in the summer under
VARQ. The discharges from Hungry Horse under the VARQ rule curves are generally
higher in May and June and lower in April when compared to Standard FC. These
discharges are reflected in the release patterns at Kerr and Albeni Falls Dams where
flows are slightly higher in June and slightly lower in April under VARQ.

Generation restrictions at Hungry Horse Dam due to transmission limitations or unit
outages can cause some increase in the amount of spill past the power plant which will
cause subsequent increases in the total dissolved gas saturation. Occurrences of total
dissolved gases exceeding 110% saturation are minor with the exception of the case of
limiting generation to three units (321 MW). Note that incidence of harm to fish from
elevated gas saturation is governed by several factors in addition to the saturation level.

There is no increase in the occurrence of flooding on the Flathead River at Columbia
Falls, Montana under VARQ. The river stage at Columbia Falls exceeded 14 feet a total
of 35 days in 14 different years for both VARQ and Standard FC. VARQ resulted in
slightly lower flows in the Pend Oreille River below Albeni Falls Dam during the March-
April time period when flooding at Cusick, Washington can be a problem. Flows in the
Pend Oreille River below Albeni Falls Dam are slightly higher in June under VARQ
when high flows from snowmelt can cause flooding problems, but the frequency of
exceeding the flood warning threshold of 100,000 cfs is essentially the same for VARQ
or Stanfield FC.